Microloge Microfiche Collection
Resolution Chart

Copyright

Copyright for the *contents* of this microfiche is held by the publisher of the original document. Please contact the original publisher for guidance in all copyright matters. Copyright in this *microfiche edition* is held by Micromedia Limited.

Quality of the Microfiche Reproduction

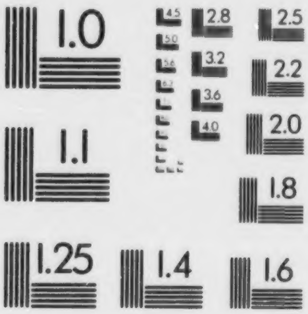
Micromedia Limited maintains the highest standards for micrographic reproduction. Attempts are made to obtain the best quality print version to microfilm. However, there are some printing styles, colours and graphic layout styles (including maps, graphs and tables) which do not reproduce well. Because of the value of the original document, Micromedia has filmed it recognizing that it may not be as easy to read as the original document.

Some pages have been filmed twice to improve the clarity of the reproduction. Consult both reproductions to ensure that all of the original text is read.

Microcopy Resolution Test Chart
National Bureau of Standards
Standard Reference Material 1010a
(ANSI and ISO Test Chart No. 2)

96
0 mm
10
20
30
40
50
60
70
80
90
100

PM-1 3½"x4" PHOTOGRAPHIC MICROCOPY TARGET
NBS 1010a ANSI/ISO #2 EQUIVALENT



MS109

NATIONAL MICROGRAPHICS ASSOCIATION

24x

---

micromedia
a division of IHS Canada

20 Victoria Street, Toronto, ON M5C 2N8
Tel.: (416) 362-5211
Toll free: 1-800-387-2689
Fax: (416) 362-6161

Collection MICROLOG sur Micromédia
Tableau de résolution

Droits d'auteurs

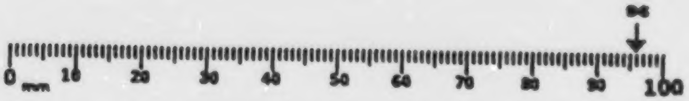
Les droits d'auteurs du conenu de cette microfiche sont détenus par l'éditeur du document original. Veuillez communiquer avec celui-ci pour obtenir des renseignements sur tout ce qui touche les droits d'auteurs. Les droits d'auteurs de cette édition sur microfiche sont détenus par Micromédia Limitée.

Qualité de reproduction sur microfiche

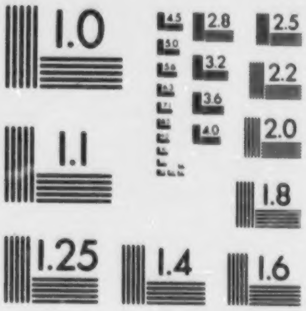
Micromédia Limitée maintient les normes de reproduction micrographique les plus élevées. Elle fait tout son possible pour obtenir la version sur papier à reproduire sur microfiche de la meilleure qualité possible. Cependant, certains styles d'imprimerie, de couleurs et de style de mise en page graphique (incluant des cartes, des grahiques et des tableaux) se reproduisent mal. En raison de la valeur du document original, Micromédia l'a reproduit tout en reconnaissant qu'il ne sera peut-être pas aussi lisable que le document original.

Tableau de résolution micrographique

National Bureau of Standards
Standard Reference Material 1010a
(ANSI and ISO Test Chart No. 2)



PM-1 3½"x4" PHOTOGRAPHIC MICROCOPY TARGET
NBS 1010a ANSI/ISO #2 EQUIVALENT



MS109

24x

NATIONAL MICROGRAPHICS ASSOCIATION

micromedia
a division of IHS Canada

20 Victoria Street, Toronto, ON M5C 2N8
Tel.: (416) 362-5211
Toll free: 1-800-387-2689
Fax: (416) 362-6161

NO PAPER RIGHTS

REIMPRESSION INTERDITE

micromedia
a division of IHS Canada

20 Victoria Street
Toronto, Ontario M5C 2N8
Tel.: (416) 362-5211
Toll Free: 1-800-387-2689
Fax: (416) 362-6161
Email: info@micromedia.on.ca

dbmc
Va er
Ca
19

Durability of Building Materials & Components 8

Service Life and Asset Management

3 Performance, Service Life Prediction and Sustainable Construction

edited by
MICHAEL A. LACASSE
and
DANA J. VANIER

NRC · CNRC

Dr. Michael A. Lacasse is a materials scientist and building science engineer who since 1991 has worked as a Research Officer at the Institute for Research in Construction, of the National Research Council Canada. His work focuses on the development of methods to assess the long-term performance of building materials and components and the durability of building envelope assemblies. Since joining the IRC, he has been active in various CIB and RILEM technical committees related to performance, durability and service-life prediction. He currently co-ordinates the activities of the joint CIB/RILEM technical committee W080/175-SLM in which issues related to the prediction of service life of building materials and components are reviewed.

Dr. Dana J. Vanier's current activities relate to service life, asset management and product modeling. He is the project manager of IRC's Building Envelope Life Cycle Asset Management (BELCAM) project, that is researching tools and techniques to help asset managers predict the remaining service life of roofing components and to better manage their assets. Dana is also involved in IRC's Municipal Infrastructure Investment Planning (MIIP) project, whose goal is to assist asset managers predict the life cycle inspection, maintenance, repair and replacement costs of urban infrastructure capital assets. He is an editor of ITCon, the *Electronic Journal of Information Technology in Construction*, and a Board Member of CIB W078, Information Technology in Construction.

NRC · CNRC Institute for Research in Construction

101-03650/

Durability of Building Materials and Components 8

Service Life and Asset Management

Volume Three
Performance, Service Life Prediction and Sustainable Materials

CORPORATE SPONSORS

The Conference wishes to acknowledge and warmly thank the following organizations and companies for sponsorship and generous support.

Canadian Wood Council
Conseil canadien du bois

Standards Council of Canada
Conseil Canadien des normes

CPCA
CANADIAN PORTLAND CEMENT ASSOCIATION
ASSOCIATION CANADIENNE DU CIMENT PORTLAND

AGRA Earth & Environmental
ENGINEERING GLOBAL SOLUTIONS

Home of the 1996 Olympic Village
Georgia Institute of Technology

Public Works and Government Services Canada
Travaux publics et services gouvernementaux Canada

ACBM

Forintek Canada Corp.

VETENSKAP OCH KONST
KUNGL TEKNISKA HÖGSKOLAN
Centre of Built Environment

National Research Council of Canada
Conseil national de recherches Canada
Institute for Research in Construction
L'Institut de recherche en construction

© 1999 National Research Council of Canada

All rights reserved. No part of this publication may be reproduced in a retrieval system, or transmitted by any other means, electronic, mechanical, photocopying, recording or otherwise, without prior written permission of the National Research Council of Canada, Ottawa, Ontario K1A 0R6, Canada.

Printed on acid-free paper

Publisher's Note: These books have been prepared from camera ready copy provided by the editors in order to make the books available for the conference.

ISBN 0-660-17742-0
NRC No. 42846

Canadian Cataloguing in Publication Data

International Conference on Durability of Building Materials and Components (8th : 1999 : Vancouver)

Durability of Building Materials and Components 8 : Proceedings of the Eighth International Conference on Durability of Building Materials and Components

Complete in 4 vols.
Includes an index.
"Vancouver from May 30 to June 3, 1999"—Introd.
Issued by the National Research Council of Canada.

ISBN 0-660-17737-4 (v.1)
ISBN 0-660-17741-2 (v.2)
ISBN 0-660-17742-0 (v.3)
ISBN 0-660-17743-9 (v.4)

1. Building materials — Service life — Congresses.
I. Lacasse, Michael A., 1953- . II. Vanier, D. J. (Dana J.) III. National Research Council Canada. IV. Title.
TA401.3156 1999 691. C99-980130-9

Inquires: Proceedings Program, NRC Research Press, National Research Council of Canada, Ottawa, Ontario K1A 0R6, Canada

Correct citation: Lacasse, M.A. and Vanier, D.J. (*Editors*) 1999. *Durability of Building Materials and Components 8: Service Life and Asset Management, Volume Three Performance, Service Life Prediction and Sustainable Materials.*. NRC Research Press, Ottawa, Canada, 575 pages.

Durability of Building Materials and Components 8

Service Life and Asset Management

Proceedings of the Eighth International Conference
on Durability of Building Materials and Components, 8dbmc

Vancouver, Canada
May 30 - June 3, 1999

Volume Three
Performance, Service Life Prediction and Sustainable Materials

Edited by

Michael A. Lacasse and Dana J. Vanier
Institute for Research in Construction,
National Research Council of Canada

NRC·CNRC
NRC Research Press
Ottawa, 1999

Contents

VOLUME ONE
SERVICE LIFE AND DURABILITY OF MATERIALS AND COMPONENTS

Preface xxix
Foreword xxxii
Acknowledgements xxxiv
Conference committees and secretariats. xxxv

PART ONE
DURABILITY OF CONCRETE MATERIALS AND STRUCTURES: SERVICE LIFE PREDICTION OF CONCRETE STRUCTURES 1

1 **Service life design for the Western Scheldt tunnel**
R. Breitenbücher, C. Gehlen, P. Schiessl, J. Van Den Hoonaard, and T. Siemes 3

2 **Degradation mechanisms and service life of concrete slabs of composite bridges**
J.-C. Dotreppe 16

3 **Service life and safety prediction of concrete slabs at filling stations**
S. Gunnarsson and J.-D. Woerner 28

4 **Estimation of service life of concrete pipes in sewer networks**
W. Kaempfer and M. Berndt 36

5 **Investigation of concrete jetties at CFB Esquimalt and prediction of future service life**
G. Ovstaas and D.R. Morgan 46

6 **The real service life of road bridges in Sweden — a case study**
G. Racutanu. 56

7 **Properties of, and service life predictions for, high performance concrete in transportation structures**
J. Ryell, M.D.A. Thomas, and P.R. Trunk 71

8 **Service life prediction of reinforced concrete structures, based on in-service chloride penetration profiles**
L. Schueremans and D. Van Gemert 83

9 **An engineered model for service life of marine concrete structures**
V. Sirivivatnanon and H.T. Cao 94

DURABILITY OF CONCRETE MATERIALS AND STRUCTURES: STUDIES ON STRENGTH AND DURABILITY OF CONCRETE 105

10 Durability of autoclaved aerated concrete
E. Bohner and K. Ödeen 107

11 Effect of matrix proportions and curing temperature on the physical, mechanical and durability properties of lime-natural pozzolan paste
A. Çolak and B. Sayil 118

12 Influence of early age thermal cracking on durability of massive concrete structures in marine environment
G. De Schutter. 129

13 Avoiding the thaumasite form of sulfate attack
M.A. Halliwell and N.J. Crammond 139

14 Fire durability of volcanic pumice concrete with special reference to thin walled filled sections
K.M.A. Hossain 149

15 Microstructure of autoclaved aerated concrete subjected to carbonation
F. Matsushita, S. Shibata, and T. Kamada 159

16 Durability of mortar linings in ductile iron pipes
I.S. Meland 170

17 Experimentation on physical durability of multilayer panels cast in situ
R. Montagna, U. Scartozzi, and M.G. Pauri 180

18 Multi-hierarchical durability assessment of existing reinforced-concrete structures
L. Mu and W. Xianming 190

19 Characterisation of impact damage in fibre-reinforced cement corrugates
B. Naji and D. Albury. 201

20 Effect of water storage time on frost resistance of concrete
K. Nordström and G. Fagerlund 212

21 Assessment and interpretation of in-situ strength of concrete
K.C.G. Ong and N. Nandakumar 222

22 Investigation and diagnosis of reinforced concrete structures in aggressive environments
I. Pepenar 231

23 Gas permeability of concrete: Definition of a preconditioning procedure for measurements and crossover trials
D. Quenard and M. Carcasses. 236

24 SO_2 environment degradation of synthetic pastes of Portland cement
C. Sabbioni, G. Zappia, C. Riontino, M.T. Blanco-Varela, J. Aguilera, F. Puertas, A. Palomo, K. Van Balen, and E.E. Toumbakari 246

25 Effect of repeated load on micro structure and carbonation of concrete and mortar
K. Tanaka, T. Nawa, H. Hashida, and J.H. Jeon 256

DURABILITY OF CONCRETE MATERIALS AND STRUCTURES: CORROSION OF CONCRETE 267

26 In-situ assessment of corrosion induced damage of the Dickson bridge deck
R. Fazio, M.S. Mirza, E. Mc Cafferty, R.J. Andrews, P.A.M. Basheer, and A.E. Long 269

27 Durability of cracked fibre reinforced concrete structures exposed to chlorides
E.J. de Place Hansen, T. Ekman, and K.K. Hansen. 280

28 EDS analysis as a prediction method for cement degradation in an aggressive environment
M. Ilic, S. Miletic, and P. Jovanic. 290

29 Prediction of concrete crack opening caused by reinforcing bar corrosion
Y. Kitsutaka and N. Nakamura 300

30 The use of galvanostatic pulse measurements to determine corrosion parameters
D.W. Law, S.G. Millard, and J.H. Bungey 310

31 The evaluation of flexural strength of RC beams damaged by rebar corrosion
H.S. Lee, T. Kage, T. Noguchi, and F. Tomosawa 320

32 Steel corrosion in concrete: a comprehensive experimental program and preliminary results
C.Q. Li, M. Cleven, and F. Isaac 331

33 **Comparison of chloride diffusion coefficient tests for concrete**
M.A. Miltenberger, J. J. Luciano, and B.D. Miller 341

34 **Prediction of corrosion resistance of concrete structures**
B.H. Oh, Y.G. Cho, S.W. Cha, and B.S. Jang 354

35 **Corrosion monitoring using a new sensor system for installation into existing structures**
M. Raupach 365

36 **A simplified method to estimate corrosion rates — a new approach based on investigations of macrocells**
M. Raupach and J. Gulikers 376

37 **Characterising chloride penetration resistance of concrete**
V. Sirivivatnanon and R.P. Khatri 386

38 **Characterization of chloride environment along a highway**
L. Tang and P. Utgenannt 399

39 **Electrolytic resistivity of cover concrete: relevance, measurement and interpretation**
R. Weydert and C. Gehlen 409

DURABILITY OF CONCRETE MATERIALS AND STRUCTURES: DESIGN AND SPECIFICATION FOR DURABLE CONCRETE 421

40 **Design of concrete to resist carbonation**
P.A.M. Basheer, D.P. Russell, and G.I.B. Rankin 423

41 **Quality control problems in high performance concrete structures**
K.A. Macdonald and D.O. Northwood 436

42 **Concrete, the durable building material**
M.R. Shirlaw 445

43 **Durable concrete through skin treatment with CPF**
J. Sousa-Coutinho 453

DURABILITY OF CONCRETE MATERIALS AND STRUCTURES: INNOVATIVE MATERIALS 463

44 **Durability of high performance concrete containing palm oil fuel ash**
A.S.M. Abdul Awal and M. Warid Hussin 465

45 **Concrete products using fine aggregate recycled from waste concrete products**
Y. Hosokawa 475

46 **Durability of polymer modified and impregnated gypsum**
B. Sayil and A. Colak 485

47 **The physical properties of polystyrene aggregated gypsum blocks**
B. Sayil and E. Gürdal 496

48 **Bearing strength of concrete containing polystyrene aggregate**
R. Sri Ravindrarajah. 505

49 **Composite scrim reinforced-cementitious boards: accelerated aging and performance prediction**
G.J. Venta, J.F. Porter, and M. Pierson 515

PART TWO
DURABILITY OF BRICK MASONRY, STONE AND TILE 525

50 **Physical and mathematical modelling of masonry deterioration due to salt crystallization**
L. Binda, E. Garavaglia, and C. Molina. 527

51 **Evaluation of site control techniques to assess the effectiveness of surface treatments on masonry**
L. Binda, G. Baronio, B. Lubelli, and P. Rocca. 538

52 **Characterisation of materials used in the replacement of sculptures in historical monuments**
F. Boutin and P. Bromblet 550

53 **Performance evaluation of water repellents for above grade masonry**
D. Chiovitti, M. Gonçalves, and A. Renzullo. 561

54 **Experimental program to evaluate building components service life: first results on brickwork**
P.N. Maggi, M.G. Rejna, B. Daniotti, F. Re Cecconi, T. Poli, G. Rigamonti, A. Jornet, and T. Teruzzi 571

55 **Comparative study of cleaning techniques applied to ancient concrete**
E. Marie-Victoire and A. Texier 581

56 **Long term migration of silicone into stone and its prevention**
M. Nakayama and M. Sasaki 593

57 **Theoretical analysis on the thermal stresses of ceramic tile coating systems**
D.A. Silva, L.M.F. Roman, M.C. Fredel, and H.R. Roman 603

58 Mapping of visual decay forms and infrared imaging of stone structures for the maintenance and monitoring studies
A. Tavukçuoglu and E.N. Caner-Saltik 613

59 Comparing laboratory and field durability testing of stone
B. Wonneberger and S.A. Bortz 624

60 Survey results regarding attitude towards stonecleaning of building sandstones
M.E. Young, J. Ball, and R. Laing 635

PART THREE DURABILITY OF WOOD AND WOOD COMPONENTS 645

61 The problem of the durability of materials used in the rehabilitation of historic timber roofs
C. Bertolini Cestari, S. Cravero, S. Curtetti, and C. Lombardi 647

62 Durability of renovated and painted wooden windows
E. Brandt 658

63 Measuring moisture content in wood with built in probes — 20+ years experience
E. Brandt and M. H. Hansen 669

64 In-service moisture content of hardboard lap siding in Southern Florida
C. Carll, A. Tenwolde, V. Malinauskas, M. Knaebe, and P.G. Sotos 680

65 Prediction of the impact of the environment on timber components: a GIS-based approach
I.S. Cole, G.S. Trinidad, and W.Y. Chan 693

66 Mathematical modelling of sorption processes in timber, based on numerical analysis
G. Dai and K. Ahmet 704

67 The residual strength of timber degraded by woodworm infestation
J.R. Gilfillan, D. Christie, and S.G. Gilbert 714

68 Protection of wood by design
M.H. Hansen and A. Nicolajsen 723

69 Designing for durable wood construction: the 4 Ds
D.G. Hazleden and P.I. Morris 734

70 Prediction of wood decay in the exterior wall of wooden houses by the deterioration of nails
H. Imamura and M. Kiguchi 746

71 **Models for timber decay and termite attack**
R.H. Leicester and G.C. Foliente 756

72 **Durability assessments of wood-frame construction using the concept of damage-functions**
M. Nofal and M.K. Kumaran 766

73 **Durability of wood**
K. Ödeen and J. Norén 780

74 **Documentation of correct use of wood protection by design**
M. Vestergaard 787

PART FOUR
DURABILITY OF POLYMER-BASED MATERIALS 799

75 **Development of a durability classification system for protective coatings for concrete**
R.S. Bassi 801

76 **Correlation of the effects of artificial and natural weathering at elastomeric building sealants**
H. Bolte and T. Boettger 814

77 **On-site non-destructive test for sealants**
M.Y.L. Chew 825

78 **New prediction methods of service life of polymeric finishing materials**
T. Fukushima 835

79 **Ceramic tile finishing systems for exterior using organic adhesives**
T. Kondo, K. Motohashi, T. Nakai, and E. Tanaka 846

80 **A new type of clear coating systems for wood**
K. Motohashi 854

81 **Service life prediction of polymeric building materials using the "acid dew and fog test"**
U. Schulz, P. Trubiroha, T. Boettger, and H. Bolte 864

82 **The effect of heat aging on acrylonitrile-butadiene-styrene (ABS) blends**
B.E. Tiganis and L.S. Burn 873

83 **The effects of ultraviolet radiation on polycarbonate glazing**
G.F. Tjandraatmadja, L.S. Burn, and M.C. Jollands 884

VOLUME TWO
DURABILITY OF BUILDING ASSEMBLIES AND METHODS OF SERVICE LIFE PREDICTION

PART FIVE
ENVIRONMENTAL CHARACTERISATION AND MODELING 899

84 **An Australia-wide map of corrosivity: a GIS approach**
I.S. Cole, G.A. King, G.S. Trinidad, W.Y. Chan, and D.A. Paterson 901

85 **Model to transform measured climatic data from a local level to a micro level: temperatures**
B. Eriksson and K. Westberg 912

86 **Moisture control in buildings — how can varying outdoor climate be allowed for?**
E. Harderup and P.I. Sandberg 923

87 **Coupled heat and mass transfer in building materials**
A.N. Noumowe, T. Ohkubo, M. Makatayama, and K. Watanabe 932

88 **Mapping rainfall distribution characteristics on facades using surface deposit geometry**
P. Snape and B. Atkinson 943

PART SIX
BUILDING FACADES AND COMPONENTS 957

89 **Durability of wall systems containing housewrap**
E.J. Bosack and E.F. Burnett 959

90 **A decision support system for preliminary design**
E.H. de Groot, S.M. Mallory-Hill, R.H.M. van Zutphen, and B. de Vries . . 970

91 **Evaluation of the long-term performance of water repellants on rendered autoclaved aerated concrete**
H. Kus and P. Norberg 980

92 **Reacting to durability problems with Vancouver buildings**
M.D. Lawton 989

93 **Dynamic buffer zone — DBZ**
C.B. Makepeace, R. Ogle, and R. Nelson 1000

94 **Foundation failures in new residential construction**
R.R. Marshall 1011

95 **Reduction of cracks in plaster revestment**
A. Müller and R.H. Romagna 1022

96 Electrical measurement of moisture content in porous building materials
P. Norberg 1030

97 Survey of the durability of the facades of 4000 dwellings in northern Portugal
V. Peixoto De Freitas, M. Sousa, and V. Abrantes 1040

98 Assessing the service life of building envelope constructions
C. Rudbeck. 1051

99 Impact of stud gauge on service life — MVSS wall
S.V. Thompson 1062

100 Investigation on the behaviour of polymer-cement composites in ETICS renderings
F. Vallee, N. Blanchard, M. Rubaud, and A. Gandini. 1070

PART SEVEN
ROOFING MATERIALS, COMPONENTS AND ROOF MAINTENANCE MANAGEMENT: ROOFING MATERIALS AND COMPONENTS . . 1081

101 Comparative testing and rating of thirteen thermoplastic single ply roofing membranes
C.G. Cash 1083

102 Effect of application temperature on adhesion of modified bitumen membrane assemblies
K. Chernotowich. 1093

103 Service life prediction of flat roofs with polymer modified bituminous waterproofing membranes
S. Croce, E. De Angelis, and A. Tiso 1103

104 Extending the durability of window washer runways
J. Henshell and P.L. Buccelato 1114

105 Experimental program for the evaluation of coil coated steel sheet service life
F. Re Cecconi and F. Ravetta 1124

106 Performance of tape-bonded seams of EPDM membranes: resistance to peel-creep
W.J. Rossiter, Jr., M.G. Vangel, and K.M. Kraft 1133

107 Improving the durability of flat roof constructions
C. Rudbeck and S. Svendsen 1148

108 Performance of strained bituminous waterproofing membranes under hydrostatic pressure
N. Sahal and E. Ozkan 1156

109 Waterproofing durability: a survey of several APP modified roof membranes in service for more than 20 years in Europe
P. Sartori 1166

110 Natural ageing of waterproofing membranes
P. Sartori, M. Becuzzi, and C. Pollastro 1178

ROOFING MATERIALS, COMPONENTS AND ROOF MAINTENANCE MANAGEMENT: ROOF MAINTENANCE MANAGEMENT 1191

111 Improvement opprotunities in roofing assets mamagement: experience from the US Army
D.M. Bailey and I. Adiguzel 1193

112 Predictive maintenance - what should be in a condition database
B.H. Hertlein 1203

113 Effective roof management — understanding the life cycle of your roof systems
C.P. Hodges 1213

114 Decision-support system for service life asset management: The BELCAM project
Z. Lounis, D.J. Vanier, M.A. Lacasse, and B. Kyle 1223

115 Condition assessment of flat roofs, including the use of expert systems
G.K. Saunders and A. Goodier 1235

PART EIGHT
PROBABILISTIC AND RELIABILITY METHODS 1245

116 A stochastic approach to the factor method for estimating service life
L.I. Aarseth and P.J. Hovde 1247

117 Development of prediction models for sewer deterioration
D.M. Abraham and R. Wirahadikusumah 1257

118 Service life with regard to frost attack — a probabilistic approach
G. Fagerlund 1268

119 MEDIC - a method for predicting residual service life and refurbishment investment budgets
F. Flourentzou, E. Brandt, and C. Wetzel 1280

120 Development of a reliability-based durability design method for timber construction
G.C. Foliente, R.H. Leicester, I. Cole, and C. Mackenzie 1289

121 Durability assessment of building systems
J. Lair, J. F. Le Teno, and D. Boissier 1299

122 Material induced structural deterioration and maintenance strategy
C.Q. Li 1309

123 Towards the practical evaluation of service life — illustrative application of the probabilistic approach
K. Moser 1319

124 Evaluating the reliability of structural masonry elements using the response surface technique
L. Schueremans, D. Van Gemert, and M. Maes 1330

125 Duracrete: service life design for concrete structures
T. Siemes and C. Edvardsen 1343

126 Failure probability of deteriorating reinforced concrete beams
B. Teplý, D. Novák, Z. Keršner, and W. Lawanwisut 1357

PART NINE
GENERIC METHODS IN SERVICE LIFE PREDICTION 1367

127 Critical loss of performance — what fails before durability
A.M. Aikivuori 1369

128 Durability of soil contaminated by oil
Y.J. AL Shakarchi and H. A. Rasool 1377

129 Durability aspects of fibre reinforced composites
S.J. Bhide and M.M. Zurale 1382

130 Field studies concerning the service life prediction
I. Gosav 1392

131 Empirical vs theoretical life prediction for subfloor structural connectors
P.W. Haberecht and C.D. Kane 1403

132 Overview and notional concepts on performance and service life
P. Jernberg 1417

133 Investigations of mass and energy flow in existing buildings
H. Kloft and J.D. Wörner 1426

134 Degradation analysis by statistical methods
B. Leira, J. Lingård, A. Nesje, E. Sund, and S. Sægrov 1436

135 Assessing the remaining service life of existing building components for insurance
P.D. Mayer and P. Wornell 1447

136 Qualitative simulation for assessment of chemical-physical compatibility among building components
B. Naticchia 1457

137 Service life prediction for floor coverings
J. Paulsen. 1467

138 Evaluation of functionality of building components applicable to service life design
M.G. Rejna. 1475

139 Phenomenological model of building material strain
O.V. Sinyayev 1485

140 Service life prediction and economic assessment of parking garage options
A. Wiseman and B.R. Kyle 1493

PART TEN
DEVELOPMENT AND USE OF GUIDES AND STANDARDS 1507

141 Life cycle costing for a design life standard
A.F. Bennett, I.C. Page, K. Bourke, S.N. Tucker, and T. Nireki 1509

142 Estimating service lives using the factor method for use in whole life costing
K. Bourke, H. Davies 1518

143 Requirements for durability and on-going performance in Canada's objective-based construction codes
G.A. Chown 1527

144 International standards for service life planning of buildings
G.J. Frohnsdorff, C.H. Sjöström, and G. Soronis 1537

145 Service life planning of building components
G. Hed 1543

146 Service life performance audit: meeting client requirements for durable buildings
G.W. Moss 1552

VOLUME THREE
PERFORMANCE, SERVICE LIFE PREDICTION AND SUSTAINABLE CONSTRUCTION

PART ELEVEN
MAINTENANCE MANAGEMENT OF BUILDING ASSEMBLIES AND FACILITIES 1561

147 **Asset governance in local government following CCT: the multi-client dichotomy**
S. Bewry and R. Kenley 1563

148 **EPIQR – a new surveying tool for maintenance and refurbishment**
E. Brandt, K.B. Wittchen, A. Faist, and J.L. Genre 1576

149 **A planning support system for management of components maintenance**
M. De Grassi and B. Naticchia 1585

150 **A tool for building refurbishment and its application**
M. Fiori and S. Croce 1595

151 **PC/GIS based system for maintenance management of wooden buildings — MMWood**
S.E. Haagenrud, B. Eriksson, C. Sjöström, and T. Skancke. 1602

152 **Preparation and prioritization of maintenance programmes**
M.R. Johnson and D.P. Wyatt 1615

153 **Development of an integrated conservation and maintenance management regime for historic modern movement buildings**
B.M. Major. 1625

154 **Overall survey buildings — performance and maintenance**
B. Marteinsson and B. Jónsson 1634

155 **Condition survey as formal and practical tool in facilities management**
S. Nes and P.J. Hovde 1645

156 **A computer-aided prioritisation framework for planned maintenance management**
Q.P. Shen 1655

157 **Deterioration patterns for maintenance management — a methodological approach**
I.M. Shohet, Y. Rosenfeld, M. Puterman, and E. Gilboa 1666

158 Assessment of building rehabilitation expediency in Bulgaria
S.N. Tzonev and D.G. Nazarski 1679

159 A service life design for lifecare management
D.P. Wyatt and A. Lucchini 1687

PART TWELVE
LIFE CYCLE COSTING AND ECONOMICS 1697

160 Modeling running and maintenance costs for life cycle costing applications in buildings
A. Al-Hajj 1699

161 Forecasting rehabilitation expenditures: the SHQ solution
R. Chamberland 1707

162 Rehabilitation and the costs to sustain dwelling services
I.M. Johnstone 1718

163 Forecasting the running costs of sport and leisure centres
R.J. Kirkham, A.H. Boussabaine, R.G. Grew, and S.P. Sinclair 1728

164 Stone cleaning: a life cycle cost model
R.A. Laing, A. Al-Hajj, J. Ball, J. Scott, and M.E. Young 1739

165 Condition survey of Toronto's highrise rental stock
S.J. Marshall and G. Genge 1746

166 Determining the impact of quality upon life cycle costs
L.A. Newton and A.J. Christian 1756

167 Accrued value assessment — a dynamic approach for investment appraisal and facilities management
T. Plenty, S.E. Chen, and W.D. McGeorge 1765

168 Real estate renovation decisions based on cost approach appraising principles
I. Pšunder 1773

169 Consideration of environmental issues when renewing facilities and infrastructure
S.F. Pullen 1778

170 Total life-cycle cost
D.K. Smith 1787

171 Facility life-cycle cost analysis based on fuzzy sets theory
J.O. Sobanjo 1798

PART THIRTEEN
PERFORMANCE AND SERVICEABILITY OF BUILDINGS: CIB W60 WORKSHOP 1811

172 The use of performance and durability data in assessment of life time serviceability
T. Anderson and E. Brandt 1813

173 Performance concept in the procurement of durability and serviceability of buildings
G.K.I. Ang and D.P. Wyatt 1821

174 Life cycle appraisal of building elements by multiple performance indicators
M. Aygun 1833

175 Ensuring building serviceability at the design stage
R. Becker. 1841

176 Communicating performance requirements — tools for transferring client-oriented maintenance information
A.A.J. Damen and M.H. Hermans. 1848

177 Are facilities measuring up?
Matching building capabilities to functional needs?
G. Davis and F. Szigeti 1856

178 Building performance starts at hand-over: the importance of life span information
M.H. Hermans 1867

179 Managing the life cycle requirements of facilities
P. Huovila 1874

180 Whole life performance strategy: beyond incremental cost and service life
D.P. Rowe 1881

181 Securing sustainable building and resource management through procurement of serviceability
D.P. Wyatt 1893

PART FOURTEEN
LIFE CYCLE ANALYSIS AND SUSTAINABLE, DURABLE DESIGN: LIFE CYCLE ANALYSIS (LCA) 1905

182 Impact of environmental, health and safety issues on coating used for offshore fabric maintenance: a LCC analysis
A. Al-Hajj and N. Thompson 1907

183 Reliability and whole life performance: integrating the supply chain
E.V. Bartlett and M. Clift 1916

184 Building durable and sustainable the Dutch way and the consequences for the healthy indoor climate
M. Ham and A. Van Bronswijk 1924

185 Life cycle assessment and the design agenda: the standards imperative
A.R. Makenya, D.P. Wyatt, and G. Soronis 1929

186 LCA as performance requirement in the Dutch building decree by 2001
N. Scholten. 1939

187 Use of service life data in LCA of building materials
S.M. Strand and P.J. Hovde 1948

LIFE CYCLE ANALYSIS AND SUSTAINABLE, DURABLE DESIGN: SUSTAINABLE DESIGN 1959

188 Analysis of dismantling vs. demolition — vision or reality
C. Boyle, B.R. Kyle, and A. Nesje 1961

189 Evaluating the sustainability of alternative window and proprietary glazing systems
A.W. Brown, S.J. Allwinkle, and G.F. Weir 1973

190 Designing for disassembly to extend service life and increase sustainability
P. Crowther 1983

191 The adoption of Hong Kong's eco-labelling scheme for buildings
H.A. Davies 1993

192 Greening of Canada's national master specification
T. Dunbar and B.R. Kyle 2002

193 Sustainability by strengthening the relation between disciplines involved
S. Durmisevic, S. Sariyildiz, E. Durmisevic, and J. Brouwer 2012

194 Product features that influence the end of a building
N.M.J. Guequierre and J. Kristinsson 2021

195 The environmental impact of insulation
N.A. Hendriks and J. de Hoog. 2033

196 Tenets of sustainable roofing
T.W. Hutchinson and K. Roberts 2039

197 Design for sustainable buildings in developing countries
A.R. Makenya and G. Soronis 2050

LIFE CYCLE ANALYSIS AND SUSTAINABLE, DURABLE DESIGN: DESIGN FOR DURABILITY 2057

198 Design for durability? — a specifier observed
S. Emmitt 2059

199 Building durability — know what you know or let's use the knowledge we already have, before we improve upon it
W.H. Gumpertz and D.A. Rutila. 2068

200 A systematic vivendi for design for durability
A. Lucchini and D.P. Wyatt 2078

201 Improvement of traditional building materials and techniques
A.B. Ngowi 2089

202 Quality control with the assurance of normative precision of geometrical parameters in erection of one-storey framed buildings
J. Parasonis. 2099

203 Design for durability — a practical approach
E. Robertsen 2107

204 Optimisation of the life span of building components
H. Tempelmans Plat 2118

205 A natural progression: neglect to decay
D.P. Wyatt 2126

VOLUME FOUR
INFORMATION TECHNOLOGY IN CONSTRUCTION:CIB W78 WORKSHOP

KEYNOTE PAPERS 2137

206 Information exchange architectures for building models
C.M. Eastman 2139

207 IAI and IFC-state-of-the-art
A. Kiviniemi 2157

PART FIFTEEN
COMPUTER-INTEGRATED CONSTRUCTION 2169

208 A prototype distributed CIC system based on IAI standards
A.L. Gorlick and T.M. Froese 2171

209 Integration of planning and control activities for building and construction: experiencing standards
R. Jardim-Gonçalves, P. Sousa, J.P. Pimentão, A. Steiger-Garcão, A. Grilo, and L. Tadeu 2180

210 Knowledge-based product data server for concurrent engineering
P. Katranuschkov and R.J. Scherer 2189

211 Lexis — an AEC industry language
H. Leslie 2199

212 A collaborative environment for building construction project toward computerization of total information
Z. Ma and J. Chen 2214

213 Information structure for integration of facility projects at operational airports
J.P. Needham and E. L. Murphree, Jr. 2224

214 First experiences with an inception support modeller for the building and construction industry
S.S. Ozsariyildiz and F. P. Tolman 2234

215 Construction information access through a "malleable frame"
Y. Zhu and R. Issa 2246

PART SIXTEEN
IT AND THE CONSTRUCTION PROCESS 2257

216 Utility assessment of electronic networking technologies in construction
M. Abduh and M.J. Skibniewski 2259

217 Improving construction communication: the impact of on-line technology
K. Al-Reshaid and N. Kartam 2270

218 Increasing on-site productivity through wireless computer control
A.H. Boussabaine, B.R. Grew, and R. Currin 2277

219 Simulation of construction operation with direct inputs of physical factors
L.C. Chao 2287

220 **Analysis of phenomenological perceptions of effectiveness of information technology in computerised maintenance management**
P. Clarke and J. Clarke. 2296

221 **I.T. Survey within the construction industry of Hong Kong**
K.G. Futcher and S. Rowlinson 2306

222 **Generic IT training: a process protocol model**
J.S. Goulding and M. Alshawi. 2316

223 **Survey of information technology and the structure of the Saudi Arabian construction industry**
M.J. O'Brien and N. Al-Biqami 2327

224 **A survey of information technology in the Canadian construction industry**
H. Rivard. 2338

225 **Integration of construction management functions**
A.H. Udaipurwala and A.D. Russell. 2348

226 **The project reporter: multimedia progress reporting for construction projects**
I.M.H. Saad 2358

227 **Information technology in the strategy of a middle-sized construction company**
S.F. Slavenburg and T.M.H. Van Straten 2370

228 **An architecture for heavy duty machine controllers — foreseeing automated road construction environments**
P. Sousa, J.P. Pimentão, R. Gonçalves, and A. Steiger-Garção 2377

229 **An automated model for generating a short-interval schedule**
A.F. Waly, W.Y. Thabet, and R.R. Wakefield 2386

PART SEVENTEEN
DECISION-SUPPORT SYSTEMS 2393

230 **Data warehousing in the construction industry: organizing and processing data for decision-making**
I. Ahmad and C. Nunoo 2395

231 **Slab formwork design using genetic algorithm**
H. Al-Tabtabai, A.P. Alex, and R. James 2407

232 **Managing and exploiting knowledge assets in the construction industry**
D. Bloomfield, I. Faraj, P. Jarvis and C. Anumba. 2419

233 Using images pattern recognition and neural networks for coating quality assessment
L.-M. Chang and Y.A. Abdelrazig 2429

234 Operations documents: addressing the information needs of facility managers
M.J. Clayton, R.E. Johnson, and Y. Song 2441

235 A integrated decision-support system model for construction management executives
A. Dikbas, B. Morten, S. Bayramoglu, and I. Yitmen. 2452

236 Co-ordination of classification for product modelling and established building classifications
A. Ekholm 2465

237 Cost estimation of high performance concrete (HPC) high-rise commercial buildings by neural networks
C.F. Fang and T.M. Froese 2476

238 Metagame analysis for determining construction methods
T. Kaneta and S. Furusaka 2487

239 Constructability knowledge-intensive database system
N. Kartam and H. Askar 2498

240 Use of automatic keyphrase generation for creation of a construction thesaurus
B. Kosovac and D.J. Vanier 2507

241 An investigation into the main information dimensions of corporate real estate management
J.L.R. Lopes 2517

242 Exploring the application of case-based reasoning to computer-assisted construction planning
J.H. Rankin, T.M. Froese, and L.M. Waugh. 2526

243 An innovative infrastructure for inter-working between dissimilar EDM solutions
Y. Rezgui, G. Cooper, and M. Vakola. 2537

244 SL/AM-IT: A CD-ROM-based, interactive bibliography on service life and durability
D.J. Vanier, M.A. Lacasse, and D.R. Payer 2547

PART EIGHTEEN
DESIGN SYSTEMS 2557

245 **Project management issues in remote CAD outsourcing**
G. Augenbroe and S. Lockley 2559

246 **Implementation of a dynamic information system for design**
S. Fridqvist. 2569

247 **Towards model based design — a case study: the modular design system**
E.D. Griffith, D.K. Hicks, K.D. McGraw, and M.P. Case 2579

248 **An internet-based distributed building design service framework**
C.S. Han, J.C. Kunz, and K.H. Law 2590

249 **Integration of parametric geometric modeling and construction simulation**
K.M. Nassar and Y. Beliveau 2601

250 **A semantically rich reference model for building design**
M.J. O'Brien and A. Baig 2609

251 **Expert validation of Tall-D: a KBS for tall buildings design**
M. Ravi and C. Bédard 2619

252 **The dynamic definition of design element specifications via a product supplier database web-site**
J. Underwood, M.A. Alshawi, G. Aouad, T. Child, and I.Z. Faraj 2629

253 **Exploring and comparing designs: the same game?**
R.F. Woodbury, S. Datta, T.W. Chang, and A.L. Burrow. 2640

254 **Improving the brief through information and process modelling**
F. Yusuf and M.A. Alshawi 2651

PART NINETEEN
LIFE CYCLE MODELS AND FACILITIES MANAGEMENT 2663

255 **Computer software architecture to support automated building diagnostics**
D.P. Chassin 2665

256 **Information analysis for roofing systems maintenance management integrated system**
M.A. Hassanain, T.M. Froese, and D.J. Vanier 2677

257 A building life-cycle information system for tracking building performance metrics
R.J. Hitchcock, P.A. Piette, and S.E. Selkowitz 2688

258 Reverse propagation of data for building management
R.W. Howard 2696

259 The benefits and costs of information technology systems in building maintenance management based on interviews
M. Naaranoja. 2705

260 Life-cycle cost design methods and tools
S. Pulakka 2710

261 Integrating permanent equipment tracking with electronic operations and maintenance manuals
D. Wirt, W.E. Showalter, and G. Crouch 2716

262 The development of industry foundation classes for facilities management
J. Wix, K. Yu, and P.S. Ottosen 2724

PART TWENTY
PRODUCT MODELING 2735

263 Examples of product model transformations in construction
R. Akbas and M.A. Fischer 2737

264 Product modeling for construction management
A. Ghanbari and T.M. Froese 2747

265 Highlights of the development process of industry foundation classes
T. Liebich and J. Wix 2758

266 Constraints of product modelling approach in building
Z. Turk 2776

PART TWENTY-ONE
PROCESS MODELING 2789

267 Measuring information integration in project teams
B.L. Atkin 2791

268 Refocusing project delivery systems on adding value
B.L. Atkin 2803

269 Cost-loaded production model for planning and control
M.A. Fischer, F. Aalami, C. Kuhne, and A. Ripberger 2813

270 Industry foundation class modeling for estimating and scheduling
T.M. Froese and K.Q. Yu 2825

271 SPICE: is a capability maturity model applicable in the construction industry?
M. Sarshar, M. Finnemore, R. Haigh, and J. Goulding 2836

272 Model based construction process management
J. Laitinen 2844

273 SYDOX/MATCOMP/XI: an information system adapted to the needs of construction actors
M. Mommessin, A.F. Cutting-Decelle, A.M. Dubois, and J.E. Dubois . . . 2864

274 Process modeling for planning and management of facilities: a re-engineering approach
P.M. Ojwaka 2876

275 The practical needs of integrating scope, cost, and time
S. Staub and M. Fischer 2888

PART TWENTY-TWO
VIRTUAL REALITY AND HUMAN–COMPUTER INTERACTION . . 2899

276 The development of an integrated life cycle costing model using object oriented and VR technologies
A. Al-Hajj and G. Aouad 2901

277 Properties of the virtual building
P. Christiansson 2909

278 The virtual building — the implications of its preparation during the design process
A.D. Dawson. 2920

279 Learning construction in virtual worlds
F.F. Ng and K.W. Chau 2930

280 Virtual construction for automated schedule generation
W.Y Thabet, R.R. Wakefield, and A.F. Waly 2939

281 Virtual reality as a design and visualisation tool in the housebuilding industry
J.K. Whyte, N.M. Bouchlaghem, and A. Thorpe 2945

Author Index A-1
Subject Index S-1

(Author and Subject indexes are included in each volume.)

Preface

Asset managers are faced with many difficult decisions regarding when and how to maintain and repair their constructed facilities. The reasons behind these difficult decisions are the growing fiscal constraints, an increasing maintenance deficit and a substantial repair backlog. In addition, asset managers' resources are being challenged from all sides: they are also being asked to cut cost, privatise operations, outsource responsibilities, reduce maintenance and increase efficiency. These problems are exacerbated by the lack of: (1) usable data, (2) information and knowledge related to maintenance, (3) repair and service life prediction techniques, and (4) tools to assist the asset manager to make proper inspection, maintenance, repair and replacement choices.

Many of these problems would be solved if more information exchange were present in the construction industry regarding service life and asset management. Many organisations have in recent years recognised the scope of the problems facing asset managers. Unfortunately existing opportunities offer only partial solutions to many of the problems in asset management. Hence there is a pressing need for research and development in this field. For example: (1) what maintenance data are required to predict service life of materials and components, (2) what are the life cycle costs of maintenance and repair alternatives, (3) what techniques are available for service life prediction, (4) how can performance be quantified using objective and representative indicators (5) how can the likelihood of failure be calculated and the consequences of failure be identified, and finally, (6) how to integrate this information to allow asset managers to make cost-effective and objective decisions on maintenance, repair and renewal alternatives?

It is within this framework that the conference themes were chosen and to which many authors have provided significant contributions to the advancement of their respective research fields. The collected body of works, presented herein, focuses on topics related to integrating existing knowledge together with the more recent contributions on service life and durability of construction and building materials, components, and assemblies. Particular emphasis has been placed on information technologies in construction and its' role in integrating knowledge through classification schemes, product models, information retrieval systems and collating and dissemination technologies.

The proceedings have been published in four volumes. The first volume, "Service Life and Durability of Materials and Components" contains four parts each reflecting those contributions made to the durability of specific building materials, namely: concrete, masonry, wood, and polymers. Within the part on concrete materials, there are several sub-sections including service life prediction of concrete structures, strength and durability, corrosion, and papers on issues related to design and innovation. The second volume "Durability of Building Assemblies and Methods of Service Life Prediction", contains six parts, the first three of which provide those papers related to environmental characterization, building facades, and roofing materials and components. Within this last area, roofing maintenance management has likewise been included as this provides the collected works in the area of roofing as a distinct part of the proceedings. The final three parts of this volume focus on methods of service life prediction, including probabilistic and reliability methods, generic methods, and lastly, development and use of guides and standards. "Performance, Service Life Prediction and Sustainable Construction" is the third volume in which the collected works are presented in four parts, starting with maintenance management, and followed by life cycle costing and economics, performance and serviceability of buildings (CIB W060 workshop), and life cycle analysis and sustainable, durable design. The final volume "Information Technology in Construction", represents those papers submitted to theCIB W78 workshop of the same name and is prepared in eight sections including computer-integrated construction, the construction process, decision-support systems, design systems, life cycle models, product modeling, process modeling, and virtual reality.

Collectively these contributions provide a selected overview of approaches, methods, techniques, tools, systems and technology used to develop knowledge on the service life durability of construction and building materials, components and assemblies and the integration of this information towards asset management. As such, it is hoped the many whohave contributed to these proceedings, as well as those who in the future will partake in perusing its many pages, will gain in an understanding of the issues, a knowledge of the techniques, some insight into the research, and healthy discernment of useful technologies.

Finally, in editing the various papers and thereafter preparing them for final copy, the editors have made every effort to produce a faithful reflection of the authors' contributions based on their revised manuscripts. However, as might be expected in proceedings of this size, and irrespective of their many efforts, the editors concede that unfortunately, but ultimately, there are likely to be found errors and omissions. These we genuinely regret and would like to express in advance our apologies for any such oversights.

M.A. Lacasse and D.J. Vanier,
Editors, 8DBMC
Ottawa, 1999

Foreword

This conference represents the 8th triennial in a series, in which the previous seven were held in Ottawa (1978), Gaithersburg (1981), Espoo (1984), Singapore (1987), Brighton (1990),Omiya (1993), and Stockholm (1996). The evolution of these collected works over the past two decades attest to the persistent and incessant pursuit of knowledge on the durability of materials, components and assemblies whether in regards to fundamental or applied research, or the most recent technological innovations. These conference proceedings have been representative of the state-of-the-art on service life prediction methods and the durability of constructed facilities.

More recently, attention has been placed on deriving from these sources of information, a means of providing practitioners with ready access to the vast body of knowledge encompassed within studies on the "durability of materials". Moreover, recent advances in information technologies permit its use as an integration tool and dissemination device, and a suitable interface to the current and evolving needs of practitioners. It is in this context that the 8DBMC provides a unique venue for exhibiting the most recent innovations in information technologies as a tool to link various research fields associated with service life prediction.

Consequently, this set of conference proceedings focuses on topics related to integrating existing knowledge together with more recent contributions on service life and durability of construction and building materials, components and assemblies. This includes work in the area of service life prediction methods and modeling, field studies and evaluation methods, degradation mechanisms, material characterization, and other related items. It is also concerned with providing a forum for new knowledge in the area of service life directly related to life cycle economics, maintenance management, performance requirement modeling, probabilistic and reliability methods, as well as, promoting the integration of this knowledge towards practical applications with emphasis on the use of information technologies as an integration tool.

These proceedings will be of interest to construction researchers, practitioners and designers concerned with service life prediction and durability as well as asset mangers interested in obtaining knowledge about the most recent innovations currently being considered as management tools. Information technologists will find considerable scope towards the application side of their emerging technologies.

These volumes are therefore a singularly valuable set of documents and a worthy addition to the previous collected works and to the annals of the Institute for Research in Construction.

Sherif Barakat
Director General
Institute for Research in Construction
National Research Council Canada
Ottawa, 1999

Acknowledgements

The preparation of this set of four volumes represents a considerable amount of focused effort by a good many capable, dedicated, and resourceful people. In this regard the efforts of those who participated in its completion must be acknowledged. Hence we are indebted to Mr. StaceyNunes for his singular efforts co-ordinating the review and processing of papers and, to Mr. Daniel Payer for his keen and assiduous work in preparing the manuscripts for publication format. As well, our sincere gratitude is extended to Mr. Pierre Lamoureux and Ms. Marie-Sophie Bourque of the 8DBMC Conference Secretariat who both insured the timely processing of the many contributions. We would also like to extend our appreciation to those at the NRC Research Press who have worked so diligently to prepare the collected proceedings for publication and imprint. In particular, mention is made of the combined efforts of Mr. Gerry Neville, Ms. Evelyn M. Kidd and Mr. Robert M. Forrest. Our appreciation is also extended to Mr. Marc Y. Boileau of the NRC Reprographic Services. Finally, this publication is made possible by the authors and also, the many and often un-proclaimed efforts of the reviewers. This collective of experts whose dedication and combined knowledge in reviewing the papers must likewise be acknowledged. The level of quality of this NRC publication is a direct result of their respected opinions.

M.A. Lacasse and D.J. Vanier
Editors, 8DBMC
Ottawa, 1999

Conference committees and secretariats

Steering Committee
Prof. Christer Sjöström, Chairman, KTH, Sweden
Mrs. Kickan Fahlstedt, Secretary, KTH, Sweden
Dr. James J. Beaudoin, NRCC/IRC, Canada
Dr. Hywel Davies, RILEM
Dr. Geoffrey Frohnsdorff, NIST, USA
Dr. Michael A. Lacasse, CIB
Ms. Anita Loots, CSIR, South Africa (Member at large)
Dr. Jonathan Martin, ASTM, USA
Dr. Kenji Motohashi, BRI, Japan (Member at large)
Prof. P. Paramasivam, National University of Singapore, Singapore (Member at large)
Prof. R. N. Swamy, RILEM

Organising Committee
Dr. Michael A. Lacasse, Conference Chairperson, NRCC/IRC, Canada
Dr. Dana J. Vanier, Conference Secretary, NRCC/IRC, Canada
Associate Professor Linda Brock, University of British Columbia, Canada
Dr. M-S. Cheung, Public Works Government Services Canada, Canada
Ms. Adaire Chown, NRCC/IRC, Canada
Assistant Professor Hitesh Doshi, Ryerson Polytechnic University, Canada
Assistant Professor Thomas Froese, University of British Columbia, Canada
Assistant Professor Gilbert Y. Grondin, University of Alberta, Canada
Mr. Noel P. Mailvaganam, NRCC, Canada
Dr. Jonathan Martin, National Institute for Standards and Technology, Gaithersburg, USA
Professor M. Saeed Mirza, McGill University, Canada
Assistant Professor Austin Parsons, Dalhousie University, Canada
Assistant Professor Hugues Rivard, Concordia University, Canada

Executive Secretarait
Dr. Michael A. Lacasse
Dr. Dana J. Vanier
Mr. Stacey Nunes

Conference Secretariat
Mr. Pierre Lamoureux, conference manager
Ms. Marie-Sophie Bourque
Mr. Laurier Forget

Technical Review Committee

Osama Al-Hunaidi, National Research Council Canada, Ottawa, Canada
Dave Allen, National Research Council Canada, Ottawa, Canada
George Ang, Ministry of Housing, Government Buildings Agency, The Hague, The Netherlands
John Archer, National Research Council Canada, Ottawa, Canada
Mark Bomberg, National Research Council Canada, Ottawa, Canada
Linda Brock, University of British Columbia, Vancouver, Canada
Adaire Chown, National Research Council Canada, Ottawa, Canada
Hitesh Doshi, Ryerson Polytechnic University, Toronto, Canada
Gilbert Grondin, University of Alberta, Edmonton, Canada
Per Jernberg, Royal Institute of Technology, Gävle, Sweden
Brian Kyle, Public Works and Government Services Canada, Ottawa, Canada
Michael Lacasse, National Research Council Canada, Ottawa, Canada
Zoubir Lounis, National Research Council Canada, Ottawa, Canada
Noel Mailvaganam, National Research Council Canada, Ottawa, Canada
Wahid Maref, National Research Council Canada, Ottawa, Canada
Jonathan Martin, National Institute of Standards and Technology, Gaithersburg, USA
Paul Maurenbrecher National Research Council Canada, Ottawa, Canada
Saeed Mirza, McGill University, Montreal, Canada
Mostafa Nofal, National Research Council Canada, Ottawa, Canada
Peter Norberg, Royal Institute of Technology, Gävle, Sweden
Stacey Nunes, National Research Council Canada, Ottawa, Canada
Austin Parsons, Dalhousie University, Halifax, Canada
Wellington Repette, National Research Council Canada, Ottawa, Canada
Hugues Rivard, Concordia University, Montreal, Canada
Walter Rossiter Jr., National Institute of Standards and Technology, Gaithersburg, USA
Claus Rudbeck, Technical University of Denmark, Lyngby, Denmark
Nady Said, National Research Council Canada, Ottawa, Canada
Michael Swinton, National Research Council Canada, Ottawa, Canada
Alan Wiseman, Public Works and Government Services Canada, Ottawa, Canada

PART ELEVEN

MAINTENANCE MANAGEMENT OF BUILDING ASSEMBLIES AND FACILITIES

147 ASSET GOVERNANCE IN LOCAL GOVERNMENT FOLLOWING CCT: THE MULTI-CLIENT DICHOTOMY

S. Bewry and R. Kenley

University of Melbourne, Victoria, Australia

Abstract

The introduction of competition has brought about dramatic changes to the maintenance service industry within Local Government in many countries. The Victorian State Government has initiated an aggressive compulsory competitive tendering (CCT) model for competition, in response to a national drive for increased competition in the provision of government services. This public sector reform follows similar reforms within the UK, the US (STEP program) and Canada (Public Service 2000 program). Implied in the Victorian approach to a more effective and efficient method of administration, management and service delivery is restructuring of organisations to reflect the needs of the customer in the services being delivered.

Out-sourcing local government services requires the service provider to consult two customers, the client (council, owner of the assets) and the customer (ratepayers, users of the assets). The structures of the organisation must be designed to reflect this dichotomy. This is exacerbated by the different approaches needed to manage internal and external service providers. Furthermore, councils are unsure of the best way to monitor customer satisfaction, which must be the responsibility of both client and provider.

This paper examines and charts the organisational structures local government have adopted in adapting to the change and also the client/provider roles, to illustrate the mechanisms used to develop a customer focus in the service delivery role. A case study approach is utilised in investigating two council's different approaches to the management of assets (buildings and infrastructure) – both policy and maintenance.

Keywords: Local Government, Service Delivery, Asset Management, Methodology.

Durability of Building Materials and Components 8 (Volume Three). *Edited by M.A. Lacasse and D.J. Vanier.* Published in 1999 by NRC Research Press, Ottawa ON K1A 0R6, Canada. ISBN 0-660-17742-0

1 Introduction

Compulsory Competitive Tendering in local government has the potential to change the way maintenance of assets is organised and managed (Bewry, 1998). As organisational structures alter, and strategies for defining the level and standard of service delivery are redefined, there is the potential to shift from centralised to decentralised management of assets.

This paper reports on the changes in the provision of local government services following the introduction of compulsory competitive tendering, and illustrates the types of structures which have flowed from the change. Examination is made of the fundamental issue of decentralisation of asset management, which has not yet been tackled in organisational structures. Generally, asset management is maintained as a client side function, which is not devolved to the role of the service provider.

2 Local Government Reform in Victoria

The 1990's are a period of significant change for governments throughout the world. The reform of the public sector has been a major economic and social issue applying to all levels of government. Increased efficiency and service delivery are expected to follow the pressure to reduce funding, as the market model is applied to public sector organisations (Hodge 1996). Increases in customer focus are expected across government as existing methods and procedures are challenged, and service delivery practices and standards are continuously reviewed against models of private sector practice. The structures, processes and service delivery mechanisms of government are increasingly under pressure from these drivers of reform. The roles and responsibilities of government are being subjected to public scrutiny, as accountability becomes more significant within the context of the provision of public services.

In recognition of the importance of achieving improved productivity and enhanced Australian international competitiveness, the Commonwealth and all States and Territories of Australia agreed in April 1995 to the implementation of a National Competition Policy (Department of Premier and Cabinet 1996). This agreement followed the report of the independent National Competition Policy Review Committee, chaired by Professor Hilmer (Independent Committee of Inquiry 1993). The Hilmer report found that, "while there had been significant progress towards improving the competitiveness of the trade exposed sectors of the Australian economy, many restrictions on competition remained within the domestic economy".

Earlier, in response to the Hilmer enquiry, local government in Victoria has been seriously impacted, through forced amalgamations and the introduction of Compulsory Competitive Tendering (CCT) in 1994. CCT represents a fundamental change to the methods local government uses in performing its duties and functions (Ernst et al, 1997). The introduction of a commercial approach contrasts with the traditional community based service approach of local government. Indicating that CCT impacts upon the operating philosophy and core values of public authorities as they change organisational structures, external relationships and human resource management to adopt the principles of the market model.

In 1994, legislation was passed by the Victorian State Government, requiring councils to expose minimum levels of expenditure (% of budget) to competition and defined the requirements for achieving these levels[1]. This approach contrasts with that previously adopted in the U.K. whereby particular services were nominated. Councils in Victoria are subject to regulatory scrutiny to ensure the competitive process is fair in practice. In complying with these requirements, Morgan (1994) suggested councils need to adopt two clearly separate roles:

- that of defining service requirements, selecting the service provider and monitoring performance (client function); and
- that of being a service provider where a council chooses to compete in the competitive process (provider function).

The restructuring of local government to achieve cost efficiency was part of a package of reforms involving:

- amalgamations;
- capped rates (fixed at current levels); and
- Compulsory Competitive Tendering.

Following the restructure of local government, a ministerial report indicated that Victoria's 78 councils (after amalgamations) achieved aggregate savings in expenditure of $328 million for the 1995/96 year (Maclellan 1996). The majority of rhetoric has focused on cost efficiency, levels of service delivery through the maintenance of assets is not easily measured. The Victorian experience remains immature, as many councils are currently adapting their organisational structures to accommodate the market model. To understand this situation better, we need to examine the international experience.

3 International experience

The restructuring of local government in Victoria is similar to that experienced internationally as governments of all persuasions are seriously considering this reform mechanism and many are adopting it vigorously.

Public sector reform through privatisation is certainly widespread on an international scale. In particular, contracting out is a key instrument in enabling public services to be provided more efficiently and effectively. Countries such as the United Kingdom and New Zealand have actively encouraged privatisation through the contracting out of public service provision. Implied in this approach to competition is a belief in the efficacy of the market, thereby introducing client - contractor relationships which mimic the operation of the market (Walsh, 1989).

Government's rationale for the introduction of competitive tendering for local authority services is the increase in efficiency generated by competition. However, Walsh (1989) argues that the intention of competitive tendering in the U.K. is not only about efficiency, but also about power. The goal is to reduce the power of both the local authorities and the trade unions. It is suggested that the policy is particularly aimed at the trade unions and the way they have colluded with local authorities to distort the working of the labour market, forcing local authorities to abandon excessively high wages and over generous conditions and recognising the local labour market conditions. Walsh (1989) concluded that contracting out fits easily into the market orientated philosophy of conservatism developed under the Thatcher government, aimed at reducing the power of suppliers of public services.

---

[1] The first year required 30% of expenditure be exposed to the competitive process, the second and third years required 40% and 50% respectively.

Government's rationale has been supported widely in the form of published reports on the positive effects of CCT on cost efficiency. Hodge (1996) reported a number of findings with regard to the economic viability of contracting out government services through competitive tendering. He concluded that the weight of evidence supports the notion that the cost of service provision is reduced. Cost savings ranged from 28% to as high as 49% for single services, most notably cleansing, refuse collection and in the 49% case, road maintenance (Hodge 1996). Although most studies appear to find that cost savings are possible on average through contracting out, the extent to which these savings accord with Domberger et al's 20% rule[2] is unclear. However, the evidence of cost efficiency is certainly not unanimous, as reported by Hodge (1996). Several studies such as Rimmer (1993) and Greene (1994) argue that contracting out makes no difference to costs.

Canadian experience with the Public Services 2000 initiative supports the notion of improving public sector operations through the introduction of private sector practice. This review of government administration attempts to improve values, cultures and attitudes. Clark (1990) argues that while government will continue to be steered by traditional values of governance such as economy, efficiency, effectiveness, probity, prudence and consistency, the best practices of the private sector will have to be adopted and adapted to the needs of government. The core values of the private sector nominated by Clark (1990) include improved client service, public consultation, results, people as valued individuals, empowerment at the point of service delivery, accountability and simplicity. Implied in this approach is the organisational structure of local government best fitting the needs of the public through service provision. However, the rationale of the Public Service 2000 initiative is to review and improve from within an organisation as opposed to simply outsourcing a role to achieve reform.

It is not clear whether cost savings in providing services under contract have impacted negatively on the quality of service provided or service levels. Domberger (1995) and Rimmer (1993) provided no consensus as to the impact on quality of service provision. Hodge (1996) collected empirical evidence to show it is possible to maintain the quality of service whilst reducing costs.

Walsh (1989) suggests that it is possible to envisage local authorities of the future to be simply a set of contracts and a network of internal and external trading. This is emphasised by the introduction of an ethos of commercialism through the introduction of competition.

---

[2] Domberger concluded that on average, contracting out in both the private and public sectors afforded a 20% decrease in costs for a given service (Domberger and Hall 1995).

4 Organisational structures

A key aspect of the introduction of CCT in Victoria is the separation of the client and provider functions. Prior to examining this issue, it is useful to provide insight as to the factors which might affect the structure of an organisation in the CCT context. Organisational theory (Robbins 1993) suggests the following theoretical imperatives or determinants of structure:

- strategy;
- organisational size;
- technology which is the information, equipment, techniques and processes utilised to provide outputs;
- organisational environment;
- power-control theory which suggests those in power selecting a structure to maintain and enhance their control.

The introduction of CCT causes the circumstances for each of the above criteria to alter. The strategy is firstly affected by the imposition of CCT, and subsequent changes related to CCT include the decision of how to package services to maximise customer satisfaction, how to drive organisational change and whether council will compete to become a provider of services. Morgan (1994) argues that the need to provide for policy development and governance functions may affect structure. Implied in this, is the power-control issue as described by Walsh (1989), suggesting that special interest groups will lobby for structures which best meet their needs or maintain their control. This is particularly relevant in the case of elected representatives being involved in the process. In the case of Victoria, the structure adopted is decided by Commissioners (appointed temporarily by the State Government), most likely on the recommendation of the Chief Executive Officer[3]. This presumably allowed organisational structures to be developed without undue influence or bias.

The importance of the separation of client and provider functions is paramount to the fairness of the competitive process (Local Government Industry Working Party 1994), suggesting that an image of structure and control is maintained to outside organisations and the public. This practice implies a process orientated, control approach to management whereby rules and procedures are integral to the structure. This case appears to fit best with a centralised management structure.

The Canadian approach fostered in the Public Service 2000 reform attempts to remove unnecessary procedural methods. Clark (1990) argues that flexibility is required to enable those business units involved in the provision of services to manage and deliver programs, concentrating on results rather than detailed procedural requirements. This approach lends itself to increasing cost efficiency of service delivery by examining existing service provision and investigating possible changes to meet customer needs through a decentralised structure. This contrasts with the approach apparently adopted in Victoria, which remains a centralised approach. Alternatively, Morgan (1994) suggests separation can be achieved by simply defining roles and establishing procedures rather than making changes to a traditional structure. Two main organisational models were proposed: the *full separation* model and the *two-hatted* model.

---

[3] The introduction of CCT was facilitated by State Government removal of elected Councillors, and the appointment of Commissioners for a 3 year term. Staged elections followed to provide for elected representatives to replace the appointed Commissioners.

Figure 1 illustrates a full separation model. The features of this model are:

- clear separation between client and provider sides of the organisation;
- client side includes CCT client functions and core functions such as governance, policy, planning, asset management, finance and human resources;
- the directors on the provider side will be responsible only for managing business units and will not be involved in policy or have a client side role;
- the CEO will have a dual client/provider role; and
- displays of the client/provider split.

Figure 2 illustrates a two-hatted model. The features of the model are:

- each director would have a dual client/provider role;
- each director would have a client unit to undertake the CCT client functions;
- the provider role comprises the business units, both in-house agreements and those services not competitively tendered;
- each director is responsible for ensuring appropriate separation between the client unit and the business units;
- the CEO and directors would be responsible for corporate planning and policy development;
- asset management may be split amongst the relevant units; and
- displays the client/provider split.

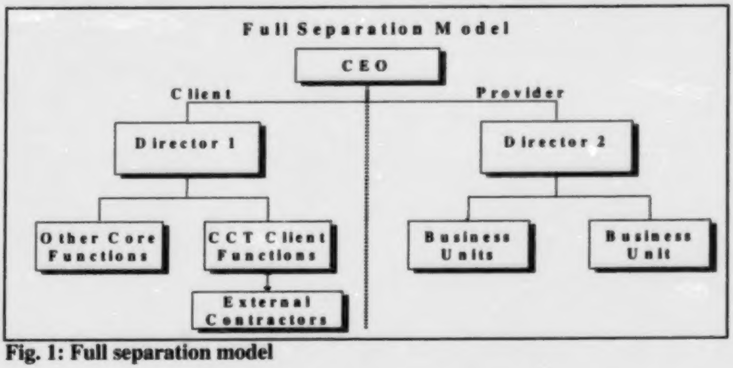


Fig. 1: Full separation model

The selection of model to be applied will have a significant effect upon the nature of operations, in particular the role of asset management. The full separation model signifies total separation of the asset management role from the provider, and ultimately the customer. Alternatively, the two-hatted model indicates a decentralised approach whereby asset management may be a role for each business unit individually.

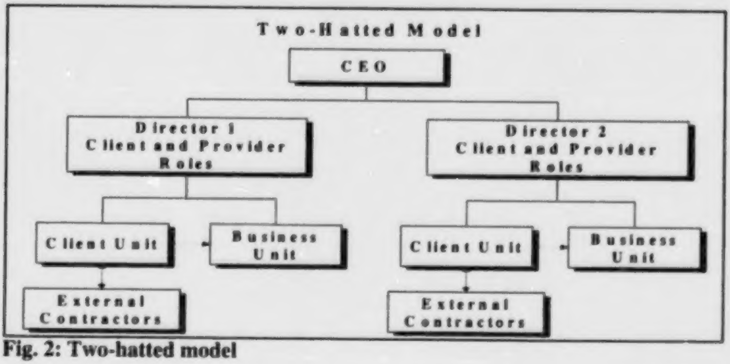


Fig. 2: Two-hatted model

5 Governance of assets

The full separation model (figure 1) maintains the governance of assets as a purely client function. Whereas the two hatted model (figure 2) devolves the governance role to the business unit involved in the service delivery function, a dual role including both client and provider management functions.

An alternative structure is proposed, a decentralised management approach, in order to maximise service delivery, and ultimately customer satisfaction through the role of asset management. The asset management role is traditionally a client side task and a responsibility seen widely as not appropriate to devolve to contractors. In achieving separation throughout the CCT processes, there needs to be appropriate technical expertise on the client side for the preparation of specifications and monitoring technical performance. However, if this expertise were available in the contractor organisation, a duplication of expertise would exist in the case of a full separation model, and perhaps adding to the costs of service provision.

Clark (1990) argues that the focus must shift from meeting client side (council) requirements to improving service through greater decentralisation of decision making. Concluding that a shift in focus would require the recognition and acceptance of risk in the short term, whilst making available innovative service delivery approaches to improve government service delivery and increasing value to the tax payer's dollar. Stewart (1989) supports this notion by suggesting that although local government is constituted for local choice, that choice is limited by organisational principles that become embedded in the culture. Further, he asserts that the devolution of management responsibility has created a clear focus in accountability to achieve the service delivery requirements.

Figure 3 illustrates the opportunity to devolve the responsibility of asset management to the provider side under a decentralised management structure in the case of local government maintenance service provision. The diagram illustrates a move of the asset management function from that of a client role (1) to a provider role (2). Implied in this approach is a decentralised management structure with a service driven asset management program. The service emphasis is supported by Dunlop (1992) who stresses that importance of customer perception and service delivery in relation to asset management.

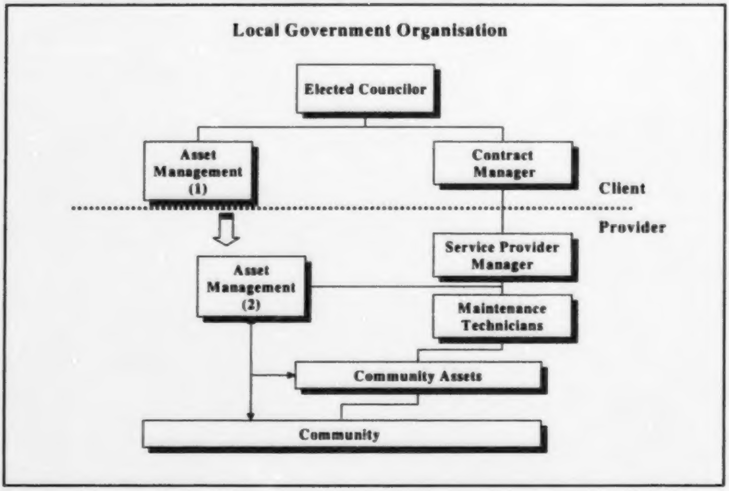

Local Government Organisation
Elected Councilor
Asset Management (1)
Contract Manager
Client
Provider
Service Provider Manager
Asset Management (2)
Maintenance Technicians
Community Assets
Community

Fig. 3: Client/provider split in local government organisation

Kenley (1997) nominated a number of benefits of this approach:

- those responsible for the direct service provision to the customer maintain a single point of contact to the customer, ensuring the appropriate level of service; and
- service levels are determined by demand-side decision making, that is, the customers requirements;

It could be argued the service provider is in the best position to determine the needs of the asset users, therefore enabling service levels to be determined by the customer requirements. As a client side role, asset management may be clearly separated from the provider and therefore not receptive to the customer. Implied in this customer focus, is the ability to provide asset maintenance to meet the needs of the customer, rather than being an asset based approach.

The client side would obviously need to ensure responsible asset management is being employed and prevent loss to the value of assets. Kenley (1997) suggested the following be adopted by the client as a governance role, to ensure performance:

- asset management plans be developed by the provider in accordance with client budgets; and
- the use of benchmarks and performance indicators.

Schreiber (1996) reported a trend within the UK and US towards performance related specifications and output rather than input measurement. Put simply, client managers are allowing industry to decide how to provide service delivery after specifying the output required. Further, Schreiber (1996) reported the control aspect is best performed by managing the output, not the input. This approach allows the provider to determine how to best achieve the desired result. However, the control or management of the desired result, or outcome, is still maintained by the client, which is generally in a position removed from the service delivery function. Thereby, the provider is in the best position to understand the needs of the customer, the end-user of the service. The structure proposed in figure 3 allows service levels to be determined by the needs of the customer, allowing demand-side decision making to maximise the use of available resources.

Outsourcing of corporate real estate management has seen an increase in the use of strategic alliances and total facilities management. A strategic alliance allows the client to utilise the strategic planning and management services of specialist industry providers. Thereby complimenting the client facility manager's role of adding value to the corporate plan. Further, the service provider and client are allowed to work and grow together with ground rules set so there are common goals and incentives driving performance. Evidence of the success of this approach was reported in FM Journal (1997), noting that the best outcomes for the customer are identified and achieved in a faster, more effective and efficient manner than the traditional contractor/client relationship. Further, the total facilities management approach allows all FM services to be outsourced and managed by one company.

The client/provider split is significant in the context of asset management in that the demand/push-supply/pull relationship may be subsequently inherited due to the non-aligning nature of decision making processes under each approach. This provides the case whereby the service provider, given a set specification or budget, attempts to push (increase) the level of service, and in effect increasing the volume and value of the activity to the provider as a business.

Alternatively, the client-side would prefer to pull (and therefore constrain) the level of service to a volume predetermined by themselves, although somewhat removed from the service provision activity, and therefore, the customer.

An example of this phenomenon could occur where the asset management role determines the service levels, as a client-side activity. The service provider provides maintenance services in accordance with the client-side requirements, irrespective of the ability of the service provider to determine the needs of the customer, particularly as they are the sole provider of services and maintain the contact to the customer. Providing further evidence of the importance of the client governance role in the case of devolution of the asset management function to the provider.

Under a decentralised management approach, devolving asset management to the provider may enable a customer focused, service driven approach to asset maintenance. Thereby ensuring the appropriate levels of service as determined by customer requirements (demand side decision making).

6 Asset governance and customer satisfaction

Figure 4 provides a representation of the key areas of consideration for the achievement of customer satisfaction under the changing structures of local government, in Victoria. Of particular consideration is the role of asset governance.

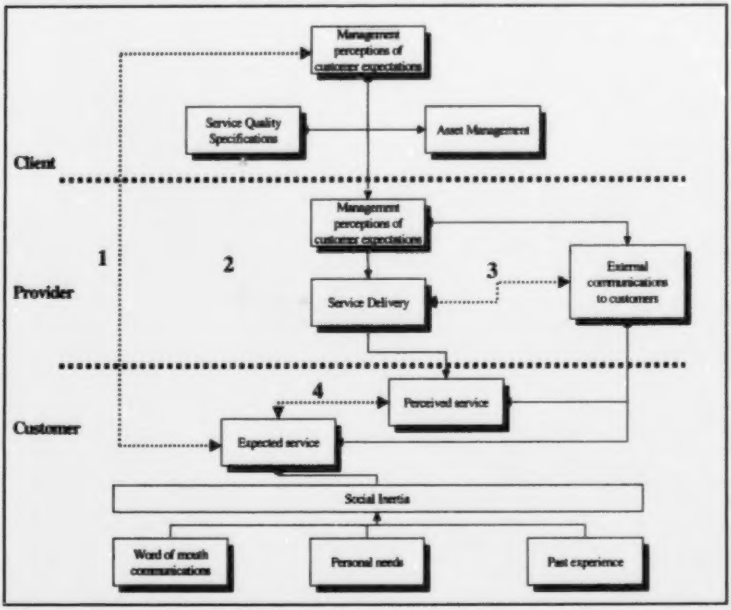

Management perceptions of customer expectations
Service Quality Specifications
Asset Management
Client
Management perceptions of customer expectations
1
2
3
Provider
External communications to customers
Service Delivery
4
Perceived service
Customer
Expected service
Social Inertia
Word of mouth communications
Personal needs
Past experience

Fig.4: Service quality model

The diagram identifies a number of gaps in the delivery of service and customer satisfaction, namely:

Gap 1. Management perception of customer expectations (client) and expected service (customer)

This gap occurs when management are out of tune with their customers, which could occur when the client is removed from the service delivery function, and misunderstand their requirements.

Gap 2. Service quality specifications (client) and service delivery (provider)

Following from gap 1, management may fail to translate their understanding of the customer's requirements into an accurate specification of the service required. If the delivery process is not designed to deliver the customers required service, there is minimal chance of delivering what the customer wants. Provided the service requirement is correctly specified, there may still be error in the performance of frontline provider personnel in actually delivering the service.

Gap 3. Service delivery (provider) and external communications to customers (provider)

This gap may occur when an organization, via external communications, raises a customers expectations beyond what the organization can or does provide. Thereby failing to meet customer expectations.

Gap 4. Expected service (customer) and perceived service (customer)

This gap occurs when personal needs, past experience and external communications regarding the service influence expectations along the ten dimensions of service quality: tangibles, reliability, responsiveness, competence, courtesy, credibility, security, access, communication, and understanding the customer (Hope and Muhlemann, 1997). Accordingly a difference will appear between customer expectations and perceptions of the service.

As portrayed in Figure 4, the customer builds their own expectation of the service delivery requirement through both soft and hard issues. Hard issues describe the measurable elements of the service encounter which can be sensed and judged against a benchmark of some description. Marsh (1998) describes the soft issues as the intangibles that deal with the subjective elements of the delivery of service and cannot easily be defined. They may include such issues as perception, trust, security and confidence. These issues are difficult for the provider to initially understand as they are subject to value judgements.

The basis of the customer's service expectation, as portrayed in Figure 4, provides a social inertia which can act as an opponent to change within the service delivery system. The ability of council of implement change may be opposed by the customers through a social inertia developed over many years of receiving services via the traditional local government method (i.e. in-house local supply). CCT drives change within the service delivery mechanism, and it is not clear that customer satisfaction is easily achievable under the recently adopted structures.

Prior to the implementation of CCT, and the subsequent adoption of new structures within councils, there was a clear distinction between the customer (ratepayer) and the service supplier (council). Under the new structures it is not clear exactly who the customer is.

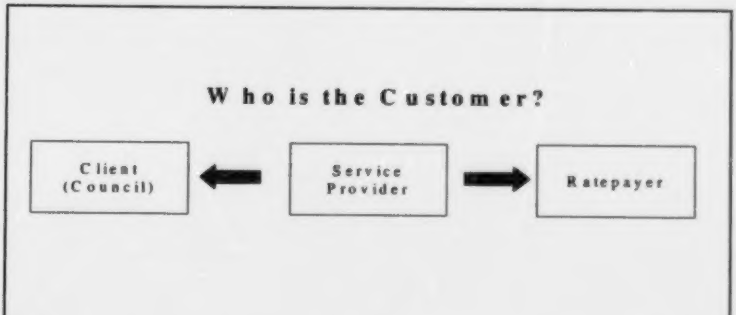


Fig. 5: Multi-client dichotomy

The council is satisfied in the case where the service provider meets the contract specification. Alternatively, the ratepayer is satisfied upon delivery of expected service to meet their requirements. It is not clear that these objectives are always aligned. Therefore, the service provider is faced with a multi-client dichotomy and conflicting incentives to satisfy each of the parties. The provider may have a contract with the client to deliver services, however, the ratepayer is ultimately the recipient of the services.

7 Further research

This paper is a preliminary report on findings associated with a major project examining the packaging of local government maintenance services. Further work will focus on the relationship between asset management and service delivery in the context of local government maintenance services, in particular the organisational decision making processes following the recent microeconomic reforms.

8 Acknowledgement

Acknowledgement and thanks is offered of support to this project by the Australian Research Council and City of Port Phillip for the provision of an Australian Postgraduate Award (industry).

9 References

Bewry, S. (1998). Development of Service Delivery through Asset Management. Fourteenth Annual ARCOM Conference Proceedings. The University of Reading. September 9-11, pp. 662-671.

Clark, I. D. (1990). "Improving Government Service Delivery." Business Quarterly v55, n2: pp85-89.

Department of Premier and Cabinet (1996). National Competition Policy and Local Government. A Statement of Victorian Government Policy: 56.

Domberger, S. and C. Hall, Eds. (1995). The Contracting Casebook: Competitive Tendering in Action. Sydney, Australian Government Publishing Service.

Dunlop, R. J. (1992). "Total Asset Management: providing the right level of service." Road & Transport Research Vol 1, No 3 (Sept. 1992): 30-35.

Ernst, J., L. Glanville, et al. (1997). Breaking the Contract. The implementation of compulsory competitive tendering policy in Victoria. Melbourne, Outer Urban Research & Policy Unit. Victoria University of Technology.

FM Facilities Asset Design Management. (1997) Facilities Management pays off in Western Australia. pp. 13.

Greene, J. D. (1994). "Does Privatisation make a Difference? The Impact of Private Contracting on Municipal Efficiency." International Journal of Public Administration Aug, 17 (7): pp 1299-1325.

Hodge, G. (1996). Contracting Out Government Services: a review of international evidence. Melbourne, Montech Pty Ltd.

Hope, C., Muhlemann, A. (1997). Service Operations Management. London, Prentice Hall.

Independent Committee of Inquiry (1993). National Competition Policy. Canberra, Australian Government Publishing Service: 385.

Kenley, R. (1996). "Decentralised Asset Management in The City of Port Phillip." Unpublished report prepared for the City of Port Phillip

Kenley, R. (1997). "Strategies for the packaging of services in Port Phillip." Unpublished report prepared for the City of Port Phillip

Local Government Industry Working Party (1994). CCT - Procedures Manual.

Maclellan, R. (1996). Competitive Tendering - Realising the Benefits
Ministers Report of the Second Year of CCT. December 1996. Melbourne.

Marsh, C. (1998). Meeting the customers needs. Construction Manager. Vol 4, Issue 7

Morgan, N. (1994). Compulsory Competitive Tendering
Models for Organisational Structure. Special Report: 60.

Rimmer, S. (1993). Aspects of Competitive Tendering and Contracting in Local Government Administration. Armidale, University of New England.

Robbins, S. P. (1993). Organizational Behaviour. New Jersey, Prentice-Hall.

Schreiber, J. (1996). Outsourcing - Management Fad or Fundamental Strategy. FM Facilities Asset Design Management. Jan/Mar. pp. 10-25.

Stewart, J. (1989). Changing Organisation of Local Authorities. The Future of Local Government. J. Stewart and G. Stoker. Hampshire, MACMILLAN: pp171-184.

Walsh, K. (1989). Competition and Service in Local Government. The Future of Local Government. J. Stewart and G. Stoker. Hampshire, MACMILLAN: p.30-54.

148 EPIQR – A NEW SURVEYING TOOL FOR MAINTENANCE AND REFURBISHMENT

E. Brandt,[1] K.B. Wittchen,[1] A. Faist,[2] and J.L. Genre[2]

[1]Danish Building Research Institute, Hoersholm, Denmark, [2]Swiss Federal Institute Technology, Lausanne, Switzerland

Abstract

Consultants and maintenance managers are often requested to inspect buildings in order to assess the conditions and to make proposals for maintenance and refurbishment actions including investment budgets. In a European project a computer-based methodology has been developed including tools for diagnosis of the building, analysis, decision making and reporting. The systematic procedure in the methodology helps to identify all major parameters affecting the performance of the building. The methodology is based on collection of available general information, a standardized visit to the building and a questionnaire. The available general information, i.e. drawings, addresses, dimensions, energy consumption etc., is collected from the owner or the manager of the building during the preparation of the visit. The visit itself is done in a systematic way assessing the building element by element using a template on a personal computer as support. During the visit also energy performance of the elements are evaluated and potential energy saving measures are noted. The indoor environment quality is evaluated on basis of questionnaires given to the residents prior to the visit. During the visit at least three flats are assessed which gives an opportunity to investigate indoor environmental problems further by interviewing the residents. Based on the findings and a comprehensive price database, the computer program gives reports on the current conditions, alternative scenarios regarding refurbishment, energy saving measures and costs for each scenario.

Keywords: Building conditions, building diagnosis, building investigations, energy performance, indoor environment quality, refurbishment, surveying.

Durability of Building Materials and Components 8 (Volume Three). *Edited by M.A. Lacasse and D.J. Vanier*. Published in 1999 by NRC Research Press, Ottawa ON K1A 0R6, Canada. ISBN 0-660-17742-0

1 Introduction - The refurbishment demand

In Europe, building maintenance and refurbishment have become of increasing importance to the building sector. According to a study by the institute Euroconstruct covering all EU member countries and Switzerland, the total construction sector represented, in 1990, 670 billion ECU (about 750 billion US$) (EUROCONSTRUCT,1990). Refurbishment and related activities represented 39% of this figure, with a growing tendency.

The demand for maintenance and refurbishment is based on the fact that a major part of the building stock was constructed in the first half of the century and now needs action in order to prolong its service life and to bring the performance up to current standards as regards insulation, wiring, sanitary installations etc. Furthermore in the sixties and seventies a large number of dwellings was constructed in big haste during the building boom in Europe. They are often of an insufficient quality and, as they were constructed before the oil crisis, often with insufficient insulation and outdated heat production systems. Rehabilitation activities in these buildings often constitute an excellent opportunity for reducing the energy consumption and often with an improvement of the indoor environment quality as well. Building refurbishment is normally considered mainly to concern the physical state of building materials and components but should also take into account related subjects such as energy consumption, function of building services, waste management, indoor environment quality and spatial comfort.

2 New tool required

Taking into account the huge amount of money required for maintenance and refurbishment, it is obviously of great economical interest to ensure an efficient assessment and handling of the works to be done. First of all it must be ensured that all information of importance to the decision process is taken into account and that this is done as objectively as possible. Next the information should be utilized thoroughly to ensure the best possible basis for decisions. For example the information should serve as a basis for an analysis of potential problems and for the planning of an intervention strategy.

Many tools and methods already exist for aid in maintenance and refurbishment problems. However, they have not been found suitable to solve the problems in the current situation. A new tool was set up which approaches projects in a pragmatic way and responds to the new requirements of the market. The target was that it should allow rapid (and therefore low-cost) collection of all data relevant to a sufficient precision of the diagnosis and it should be able to respond to market fluctuations in the building sector. Furthermore, the developed tool should be accessible to a wide range of people working in the building sector e.g. architects, engineers, surveyors and technicians, who are not necessarily specialists in building investigation, or building pathology.

To meet these requirements the tool should be easy to use, guide the surveyor through the data collection, help to reveal the possibilities of energy saving and indoor environment improvements and, last but not least, calculate the costs for all proposed actions and report the findings in a standardized way.

2.1 EPIQR - a new tool

In a European project sponsored partly by the EU and partly by a number of national bodies, a new tool was developed on the basis of the demands mentioned above. The project EPIQR (Energy Performance Indoor environment Quality Retrofit) was launched in 1995 and finished at the end of 1998. It was carried out in collaboration between:

- Building Research Establishment (BRE, United Kingdom) Project coordinator
- Centre Scientifique et Technique du Bâtiment (CSTB, France)
- Danish Building Research Institute (SBI, Denmark)
- Fraunhofer Institut für Bauphysik (IBP, Germany)
- National Observatory of Athens (NOA, Greece)
- Building and Construction Research (TNO, The Netherlands)
- Ecole Polytechnique Fédérale de Lausanne (EPFL, Switzerland)
- G.A. Meylan (Lausanne, Switzerland)
- GS Arkiteckten AG (Münchenstein, Switzerland)

EPIQR is a computer-based methodology including tools for diagnosis, analysis, decision-making and reporting. It is based on previous methodologies used in Switzerland (Genre, J.-L.et al., 1992). The target audiences are building surveyors, architects, engineers, owners and managers. It concerns the first phase of refurbishment projects, figure 1, and encompasses every step from the first decision to assess the building is taken to the providing of different refurbishment scenarios as an aid in the decision process of whether and how maintenance and refurbishment should be done.

EPIQR uses a systematic diagnosis formalism in order to determine the current state of deterioration of each element and its impact on energy consumption and indoor environment quality. Interacting with a large database of costs, energy consumption, indoor environment quality and upgrading possibilities, the EPIQR user can review different refurbishment scenarios. For each scenario the method calculates the global refurbishment cost and the energy requirement of the new situation. A cost analysis is possible using the EPIQR cost database with more than 900 detailed refurbishment reference costs set up for each of the participating countries.

Recent developments in the IT technology enabled the integration of different software modules. The user-friendly EPIQR software uses database technology to organize information and multimedia possibilities to illustrate it. The open structure of the software package offers the possibility to each country to adapt the method to local particularities and construction modes.

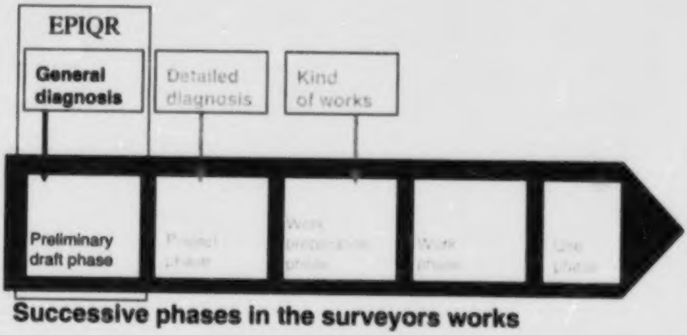

EPIQR
General diagnosis
Detailed diagnosis
Kind of works
Preliminary draft phase
Project phase
Work preparation phase
Work phase
Use phase
Successive phases in the surveyors works

Fig. 1: EPIQR in the general renovation process has its place in the preliminary phase

3 EPIQR diagnosis

The basis for the EPIQR methodology is a systematic inventory of the current building condition based on objective assessment of critical parameters, achieved by:

- A visit according to a standardized procedure to determine the current state of the building materials and components
- Information from the management about the current energy consumption and an assessment of potential energy saving measures.
- Information about indoor environment quality gathered from a questionnaire.

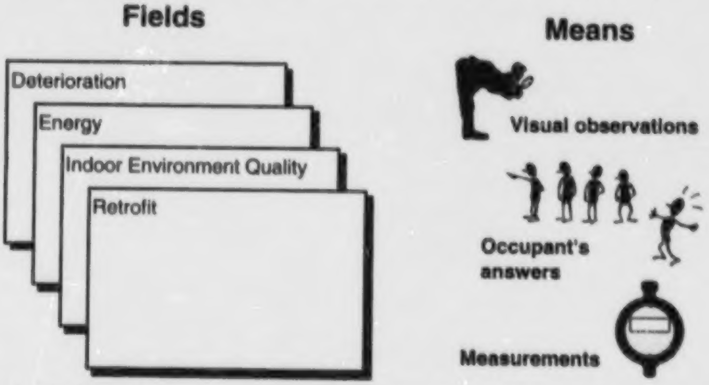

Fields
Means
Deterioration
Energy
Indoor Environment Quality
Retrofit
Visual observations
Occupant's answers
Measurements

Fig. 2: The EPIQR database contains different subjects. Data are gathered through visual observation and occupant interviews

In order to facilitate the investigator's assessment and to ensure a correct judgement of the situation, the advantages of multimedia are used thoroughly, both through text and images, in the inventory. All information is entered into databases on the different subjects. The databases related to the various subjects, i.e. deterioration, energy, indoor environment quality, etc. can be adapted to local particularities and evolve as a function of more precise and complete knowledge of the domain.

3.1 The visit

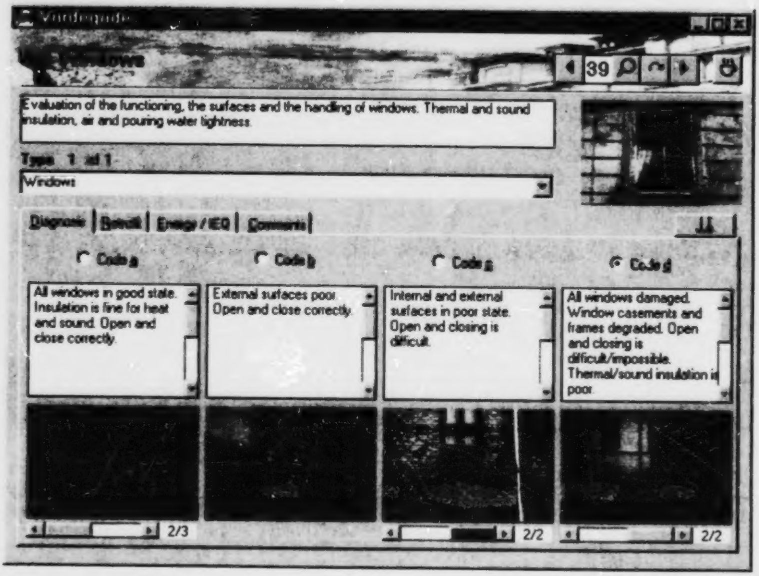
Before the visit all available information about the building(s) is collected from the owner or the manager of the building and entered into the database, i.e. location, use, types of materials, age, management and current energy consumption. Energy consumption is used in the EPIQR software to situate the building relative to the national average. Likewise information from previous surveys may be relevant.

The visit itself is done in a systematic way. In the methodology the building is sub-divided into 50 elements which are assessed element by element using a template on a portable computer as support. The condition of each element is classified in one of four degradation classes designated "a", "b", "c" and "d", where "a" signifies elements in a good state whereas "d" signifies a very deteriorated element which should be replaced. The classification criteria are explained as text and illustrated by photos from a national database, giving examples of building elements belonging to each type and class, see figure 3. All findings/classifications are entered directly into the template. During the visit energy performance of the elements are also evaluated and potential energy saving measures can be noted.

The visit will normally take a few hours (2 to 6 hours) dependent on the size and complexity of the building. The methodology used for the visit also exists in the form of a booklet, which contains all building elements and criteria.

3.2 The questionnaires

Before the visit questionnaires about indoor environment problems are distributed to the occupants. The answers help the auditor to identify indoor environment problems and other problems, which may not be visible at the time of the visit. For example it is not possible to see if there is a problem with insufficient heating under winter conditions, during a visit in the summer. The results of the questionnaire can be supplemented by interviewing some of the residents during the visit.



Evaluation of the functioning, the surfaces and the handling of windows. Thermal and sound insulation, air and pouring water tightness

Windows

○ Code a

All windows in good state. Insulation is fine for heat and sound. Open and close correctly.

○ Code b

External surfaces poor. Open and close correctly.

○ Code c

Internal and external surfaces in poor state. Open and closing is difficult.

● Code d

All windows damaged. Window casements and frames degraded. Open and closing is difficult/impossible. Thermal/sound insulation is poor.

Fig. 3: The degree of deterioration of the 50 EPIQR elements is described and coded "a" to "d". The text is illustrated with typical examples

4 Refurbishment scenarios

In a special interface, all information collected in the diagnosis phase is summarized. Additional information for any specific building element is available concerning national standards and guidelines, indoor environment quality and energy savings. Energy calculations give information on the energy saving potential of each action as it is possible to calculate the potential energy savings by improving a building element and compare to the current conditions. For each action there is feedback on the refurbishment costs sub-divided into the detailed works. Further, the costs obtained from the EPIQR database can, if necessary, be adjusted by the surveyor to fit the particular project better. All costs can be changed and new works added.

This information can help the surveyor decide what maintenance and refurbishment actions to suggest. The proposals are given as refurbishment scenarios and it is possible to make scenarios with emphasis on different themes, i.e. energy savings, indoor environment and low investments. Each scenario lists the required/-proposed actions with an associated budget.

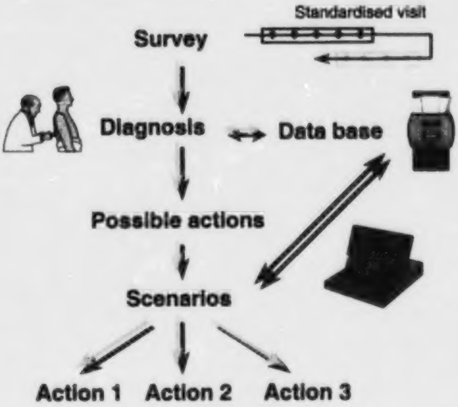


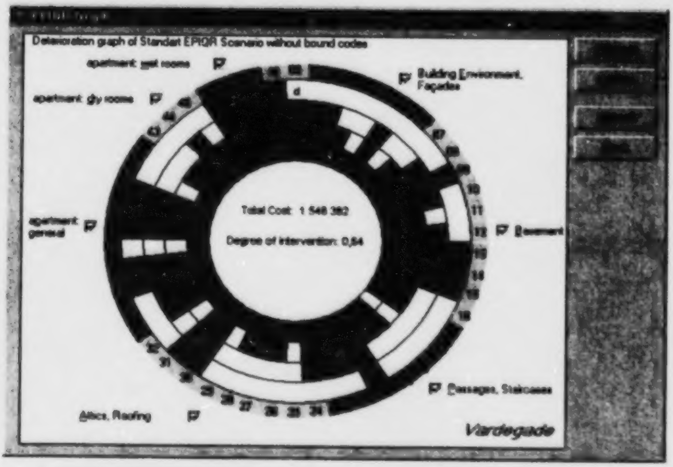
Fig. 4: The EPIQR concept - The complete catalogue of possible actions allows different refurbishment scenarios

The scenarios can be used by the building owner and/or manager as a basis for decisions on which actions should be taken, dependent on the maintenance policy, priorities and/or budget limitations.

5 Reports

EPIQR offers the possibility of producing different reports automatically dependent on the results of the diagnosis and the chosen scenario. The surveyor is therefore able to present a complete report to the building owner/manager including not only the building diagnosis but also a presentation of different scenarios for the future maintenance and refurbishment.

The indication of the global cost is accompanied by a detailed description of related work with associated costs, classified according to building elements or professions (masonry work, carpentry etc.). A probabilistic model simulates the evolution of the global maintenance and refurbishment cost for the next 15 years (figure 6). This will be a really useful tool for the financial planning of building refurbishment and the choice between possible scenarios.



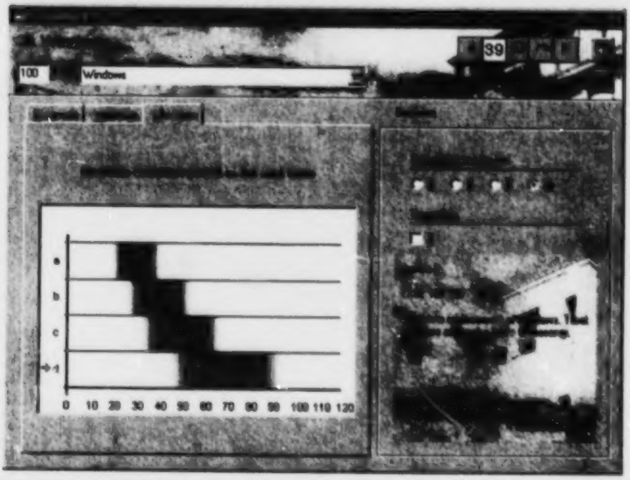
Deterioration graph of Standart EPIQR Scenario without bound codes

Total Cost: 1 548 382

Degree of intervention: 0,84

apartment: wet rooms
apartment: dry rooms
Building Environment, Façades
apartment: general
Basement
Passages, Staircases
Attics, Roofing
d
7
8
9
10
11
12
13
14
15
16
24
26
27
28
29
30
31
32
43
44
45
49
50
Vardegade

Fig. 5: An interactive graph visualizes the deterioration codes or costs of the 50 building elements. Choosing different scenarios immediately results in an illustration of the consequences



39
100
Windows
a
b
c
d
0
10
20
30
40
50
60
70
80
90
100
110
120

Fig. 6: Simulation of the development in degradation code, based on the current code and age of the building element and statistical information on the degradation of such building elements (Flourentzou F. et al., 1998)

6 Extension of the methodology

The EPIQR tool has been developed solely for use in residential buildings. The EPIQR databases were set up for 7 countries each in their national language. The open structure of the software allows adaptation to new ones.

However, it is believed that it can relatively easy be adapted to other building types such as schools, hotels and office buildings which might contain somewhat different elements and where focus is on problems slightly different from those found in residential buildings. A similar project, TOBUS (A decision making Tool for selecting Office Building Upgrading Solutions), concerning office buildings was started in September 1998.

7 Conclusion

It has been shown during the project that EPIQR allows a rapid and comprehensive inventory including reporting. The software makes it possible to utilize the information acquired through visual observation and interviews with the occupants comprehensively. Different refurbishment scenarios can easily be elaborated as a basis for choosing the one that best fits the specific situation i.e. the financial possibilities and the need of reducing the energy consumption and improving indoor environment quality.

Finally EPIQR could easily be adapted to other countries, and even other building categories or other sectors.

8 References

EUROCONSTRUCT, European construction to 2000, St. Galler Zentrum für Zukunftsforschung (SGZZ), St. Gallen, Switzerland.

Flourentzou F., Genre J-L, Faist A., MEDIC: prediction method of probable deterioration scenarios and refurbishment investment budgets, EPIC conference, Lyon 1998.

Genre, J.-L., Marietan, S., Meier, E., Meylan, G.A., Kholer, N., Rumo, N., Rüst, B., Rutz, M., " Méthode de diagnostic sommaire MERIP", Office fédéral des questions conjoncturelles, Bern, Switzerland, 1992.

149 A PLANNING SUPPORT SYSTEM FOR MANAGEMENT OF COMPONENTS MAINTENANCE

M. De Grassi and B. Naticchia

University of Ancona, Italy

Abstract

Building maintenance can be roughly viewed as a suitable set of actions which tends to restore performance levels of components to acceptable values. The main difficulty in the planning of this activity pertains to the problem that any performance is usually linked to a variety of feature of building components so that a maintenance operation can't be bounded to a simple repair action but frequently involves a set of coordinated actions aimed to remove any cause of possible fast degradation. Furthermore the planning of the operations is performed under uncertainty about the real cause of any degradation process and the effectiveness of the rehabilitation strategy selected. To this aim, maintenance planning implies the organization of an effective sequence of operations with particular regard to their reciprocal technical interrelation. In this paper, we develop a formulation of repair planning integrated in a diagnosis model and describe a repair algorithm aimed to compute optimal sequences of observations and actions. Our approach generates rehabilitation plans in the face of uncertainty about building state, trustworthiness of observations, as well as the effect of repair actions. Included in our approach is a Bayesian-network representation in order to formalize effective model-based diagnosis of observed failures. Integration of diagnosis and repair actions in a unique decision-theoretic model allows to conceive a dynamic planning which reacts to the updating of state of information about the system conditions and effectiveness of repair procedures. The approach proposed in this paper could be a contribution in dealing with the problem of envisioning the overall structure of maintenance process and managing the information flow among process actors. The decision-theoretic discussed is under implementation in a support system capable of automatic generation of planning schedules about maintenance operations and runtime advice about technical dependencies among repair operations.

Keywords: Building maintenance planning, automatic operation scheduling.

Durability of Building Materials and Components 8 (Volume Three). *Edited by M.A. Lacasse and D.J. Vanier*. Published in 1999 by NRC Research Press, Ottawa ON K1A 0R6, Canada. ISBN 0-660-17742-0

1 Introduction

Given that a device is not working properly or a patient has some complaint, automated-diagnostic systems have traditionally been designed to determine the set of faults or diseases that explain the symptoms (de Kleer and Williams 1987; Genesereth 1984; Heckerman et al. 1992; Breese et al. 1992). The diagnostician is able to ask questions about the behavior of the device or test individual components in order to determine if they are working properly. As new information is gained, the procedure updates its current view of the world. Inference focuses on identifying the set of faults consistent with the observations and, in the probabilistic case, assigning probabilities to the feasible diagnostics. Information gathering proceeds until the current diagnosis is sufficiently restricted to support action. From a decision making perspective, however, our primary objective is to repair the device or restore the building, not just determine what is wrong. At any stage of the process, there are many possible observations, tests, or repairs that can be applied. Because these operations are expensive in terms of time and/or money, we wish to generate a sequence of actions that minimizes costs and results in a re-established right performances. In this paper, we develop a diagnostic procedure, amenable to be automated in a planner, that gather evidence about the state of the building components and then selects the next best repair action by estimating the expected cost of repair for various plans. Our approach is closely related to the decision-theoretic method for troubleshooting of non functioning devices drawn in (Heckerman et al. 1994; Heckerman et al. 1995) and to the hierarchical repair strategy discussed in (Srinvas and Horvitz 1995). The diagnostic process based on bayesian networks, a specific class of belief networks, is described in large body of literature. We refer to following basic works for key concepts and terminology related to these issues (Pearl 1988, 1996; Shachter 1990; Jensen 1996; Spirtes et al. 1993).

2 The diagnostic reasoning

Let us consider the steel frame sketched in figure 1 which needs structural rehabilitation because of a high displacement δ measured in the middle of the span.

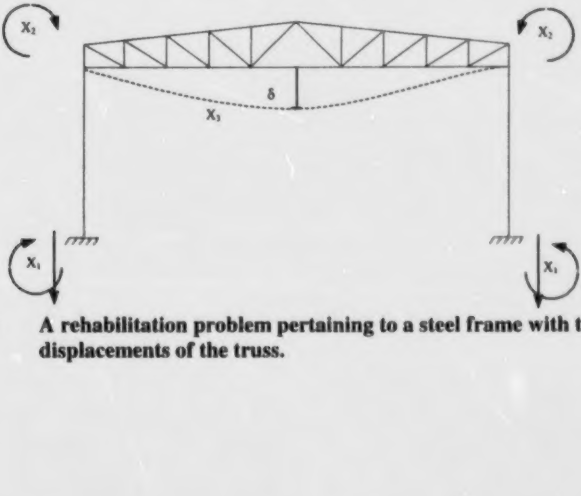


Figure 1: **A rehabilitation problem pertaining to a steel frame with too high displacements of the truss.**

The problem of diagnosing the cause of excessive displacements is amenable to representation in the form of bayesian network and can be solved using standard belief network inference algorithm.

The fragment of the network representation of a structural diagnosis problem is shown in figure 2. The arcs of the network represent direct influences between random variables relevant for the phenomenon. The direction of an arc is assigned in agreement with intuitions about causality. For example the diagram represents the qualitative information that high displacements δ might depend on high foundation movements (X_1) and/or high strain of joints (X_2) and/or high girder elements strain (X_3). Moreover, because bayesian network allows us to capture quantitative information about conditional independence, it make it possible to compactly represent joint distribution over all variables of the problem, giving conditional probability distributions for each node.

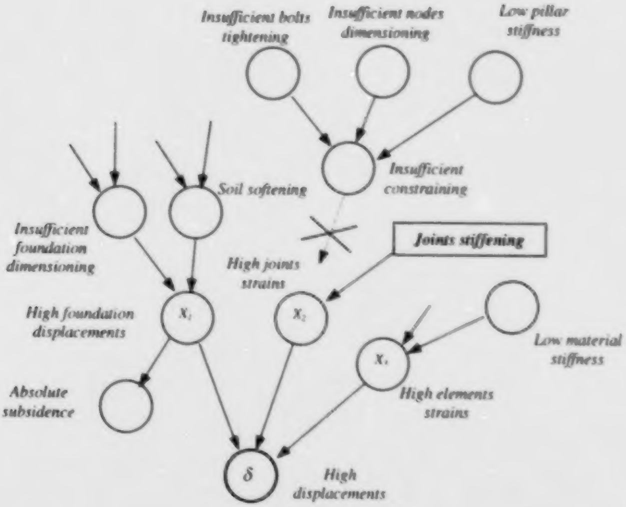

Insufficient bolts tightening
Insufficient nodes dimensioning
Low pillar stiffness
Soil softening
Insufficient constraining
Insufficient foundation dimensioning
High joints strains
Joints stiffening
High foundation displacements
X_1
X_2
X_3
Low material stiffness
Absolute subsidence
High elements strains
δ
High displacements

Figure 2: **A rehabilitation problem pertaining to a steel frame with too high displacements of the girder.**

To solve the problem of rehabilitation we could use the network in order to perform a probabilistic inference about the most probable cause of the defect with the current information state. Information state pertains to base observations (observations of the problem defining variables) and non-base observations (observations of non defining variables that share influences with defining variables); for example the observation of an absolute subsidence of the frame with respect to neighboring buildings is a non base observation that increases the probability of important foundations subsidence.

Bayesian networks are parameterized by conditional probabilities and offer the ability to explicitly represent dependencies among random variables at arbitrary levels of detail. They take the form of directed acyclic graphs whose nodes represent random variables and whose edges represent probabilistic dependencies. Under a causal interpretation, the edges represent direct causal influences that are quantified by probability distributions associated with the nodes. While the interpretation of Bayesian networks was suggested by causal considerations, the formal semantics make no reference to causality. Because Bayesian networks allow us to capture information about conditional independence (that is, any pair of variables, depicted as nodes in the graph, which are not directly connected are assumed to be conditionally independent), they make it possible to compactly represent probability distributions. The probability distribution corresponding to a Bayesian network may be specified by giving conditional probability distributions for each node in the network. The conditional probability distribution gives the probability of the random variable taking on each possible value conditioned on each combination of values of its parent nodes. If the node has no parents (a 'root' node), one specifies a prior distribution over the values of that node.

Bayesian networks achieve an economical representation of a joint distribution over the variables involved by specifying, for each variable, x_i , the conditional probabilities $P(x_i|pa_i)$ where pa_i are a set of predecessors (of x_i) which render x_i independent of all its other predecessors. Variables judged to be the direct causes of x_i satisfy this property, and these are depicted as the parents of x_i in the graph.

Given this specification, the joint distribution is given by the product

$$P(x_1,\dots,x_n)=\prod_i P(x_i \mid pa_i)$$

from which all probabilistic queries can be answered coherently using probability calculus. In fact because the Bayesian network determines the joint probability distribution, we can, in principle, use a Bayesian network to compute any probability of interest. For example the classical probabilistic inference in a diagnosis process is the evaluation of $P(x_k|x_z)$ where z is an evidence and k is an hypothetical explanation; using the rules of probability we have

$$p(x_k \mid x_z)=\frac{p(x_k,x_z)}{p(x_z)}=\frac{\sum_{\{x_1,\dots,x_n\}\setminus\{x_k,x_z\}} p(x_1,\dots,x_n)}{\sum_{\{x_1,\dots,x_n\}\setminus\{x_z\}} p(x_1,\dots,x_n)}$$

However when we actively set (as opposed to passively observe) the value of a variable in a Bayesian network (i.e. with a repair action), previous observations regarding device behavior may change because any action that changes the configuration of the frame may change the causal mechanisms of the system. So once a repair has been carried out, we must remove all observations that correspond to nodes that are descendants of the repair action node, because the repair action could have changed these observations. Moreover, we must delete all the nodes that are ascendants of the repair action node, because the repair action has made the descendants and the ascendants of that node causally independent.

For example to represent the rehabilitation operation of stiffening joints of the frame, in the network of figure 2, we delete all the incoming links in the node of the variable 'High strain of joints' and fix value of the variable to 'no'. Note the difference between the action (High strain of joints=no) and the observation 'High strain of joints=no'. The latter is encoded by ordinary Bayesian conditioning, while the former by conditioning a mutilated graph. This mirrors indeed the difference between seeing and doing: after observing that strain of joints are high we wish to infer that the dimensioning of the frame nodes is insufficient, or that the tightening of bolts is insufficient and so on; no such inferences should be drawn in evaluating the effects of the contemplated action 'joints stiffening'.

There is no mechanism in a single static Bayesian network to combine the observations before and after this action. In this paper, we recall a notion called persistence introduced in (Heckerman and Breese 1996), and show how it can be used as a solution to this problem in the context of rehabilitation planning. We refer to (Colajanni 1991) for the key concepts and terminological issues about application of planning in architectural field.

In the remainder of this paper, we firstly expose the paradigm of basic rehabilitation planning which performs only an offline optimization of the operations sequence. Then the case of runtime planning optimization is discussed; in this case repair action are meshed with observations of both the state of the system and the effectiveness of the repair operations.

3 Basic rehabilitation planning

Let X be the set of variables $\{x_1, x_2, \ldots, x_n\}$ representing the behaviors of components of the building system that we are examining. We shall assume that each component or performance x_i is in exactly one of a finite set of states. By convention, we use 'x_i=ok' to denote the event that component x_i is in the state of working properly.

Let Y be the set of variables $\{y_1, y_2, \ldots, y_m\}$ representing the set of observations that one can potentially make about the building system in question, with each y_i taking on exactly one of s_i possible states $\{y_{i1}, y_{i2}, \ldots, y_{is_i}\}$. We write y_i=k to indicate that observation y_i takes on state k.

In this paper, we assume there is a distinguished observation z that denotes the functional state of the building. We use 'z=ok' to denote the event that the building performances are in the normal ranges. We assume that both repairs and observations can have nonzero cost. Cost-effective maintenance is the development of a plan with minimum expected cost.

In this framework, an observation is valuable only if the expected cost of repair given that observation is less than the expected cost of rehabilitation procedure in the absence of that observation. This type of analysis is called 'value of information analysis' in the field of decision analysis, because we are explicitly calculating the expected value of various observations in terms of their subsequent effect on actions. A decision tree for optimal plan search in a simple problem is shown in Figure 3. It shows the decision framework in a rehabilitation problem connected with a failure of a bearing wall in a building. In drawing this model, we have assumed that the costs of repair are independent, that the defect will be fixed if one operates both on foundation capacity and on wall capacity of bearing stresses deriving by horizontal displacements of the upper floor slab (i.e. making a fastener beam on its upper side).

Moreover we have assumed that only variable y_1 can be observed.

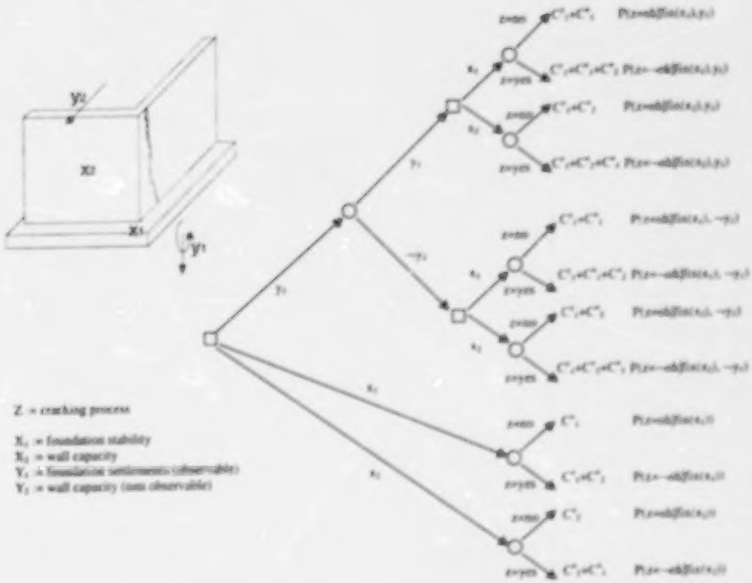

y2
x2
x1
y1
z=ok
z=yes
Z = cracking process
X1 = foundation stability
X2 = wall capacity
Y1 = foundation settlements (observable)
Y2 = wall capacity (non observable)

Figure 3: A decision tree for optimal planning of a rehabilitation problem.

The values at the end of the tree are the cumulative costs of observations and costs of repairs along the path from the root. We use C^y_i and C^a_i to denote the cost of observing the variable y_i and repairing component x_i respectively.

The expression $P(z=ok|fix(x_i);y_j)$ is the probability that the building performances are in the right ranges, given that we have repaired component x_i and have observed y_j before repair. We call such probabilities repair probabilities.

The expected cost of a repair sequence defines the (negative) value of that sequence. In Figure 3, the expected cost of repair for the sequence with no observations and repairing x_1 first is

$$P(z=ok|fix(x_1))C^a_1+(1-P(z=ok|fix(x_1)))(C^a_1+C^a_2)$$

this expression assumes that repairing both x_1 and x_2 is guaranteed to fix the problem.

Under particular assumptions (there is exactly one cause responsible of the failure, the costs of observation and repair do not depend on previous actions, if an observable component behavior is observed to be abnormal the rehabilitation of the component is immediately performed, no observations, other than the observation-repair of a component, are undertaken during the course of rehabilitation progress), it is possible to generate an optimal sequence of rehabilitation operations under uncertainty without enumerating a decision tree or equivalent search procedure.

For this purpose let p_i=P(z=ok|fix(x_i),I) be the repair probability that the behavior will be right, given x_i is repaired and under the current state of information I including information about previous observations as well as rehabilitation operations. If we observe and possibly repair components in the order {x_1, x_2, … , x_n}, the expected cost of rehabilitation under state of information I is given by:

$$\mu_C = \sum_{i=1}^{n}\left[\left(1-\sum_{j=1}^{i-1} p_j\right)C_i^{xy}\right]$$

where C^{xy}_i is the expected cost of the observation-repair action performed on component behavior i, given by $C_i^{xy} = C_i^{y} + p_i C_i^{x}$ for observable an component behavior and given by $C_i^{xy} = C_i^{x}$ for an unobservable component behavior.

The preceding equation says the expected cost of rehabilitation consists of the cost of observing and repairing the first component, and if that rehabilitation is unsuccessful (with probability 1-p_1) then we incur the cost of the second component, and so on. (Kalagnanam and Henrion 1990) have shown that the minimum expected cost sequence is obtained by ordering the operations according to a decreasing probability to cost ratio. The expected cost of repair is understood to be that under the component ordering where

$$\frac{p_1}{C_1^{xy}} \geq \frac{p_2}{C_2^{xy}} \geq \ldots \geq \frac{p_n}{C_n^{xy}}$$

4 Computing repair probability in dynamic planning

The problem we have to solve at this step, is the computation of repair probabilities. As formerly stated, in our approach, we compute these probabilities using a Bayesian network. For example, given the observation that 'Foundation movements' is false, we can use a Bayesian-network inference algorithm to compute the probability that any or all of the building components have a defective behavior. However when we wish to recalculate probabilities given a component has been manipulated, updating procedures must account for the change in underlying state of the device and the fact that previous observations may have been invalidated.

Consider the simple causal relationship between the foundation settlements, which we model as having values 'low' or 'high', and the cracking process in the supported wall, which we model as having states 'inactive' and 'active'. The two nodes are dependent as depicted in the bayesian network in figure 4a.

Now suppose we observe the wall cracking to be 'active', and we want to determine the probability that the 'wall cracking' will be 'inactive', after we make sure the 'Foundation settlement' is halted. We can do so, using the Bayesian network shown in Figure 4b. In this network 'Foundation settlement$_{\text{pre}}$' and 'Foundation settlement$_{\text{post}}$' represent whether or not the settlement is halted, respectively before and after we consolidate the foundation. Similarly, 'Wall cracking$_{\text{pre}}$' and 'Wall cracking$_{\text{post}}$' represent whether or not the cracking process is active before and after we make the foundation firm, respectively. The node 'm$_{\text{Wall}}$' represents all of the possible mappings between 'Foundation' and 'Wall'. This node is called 'mapping node' while the remaining nodes 'domain nodes'.

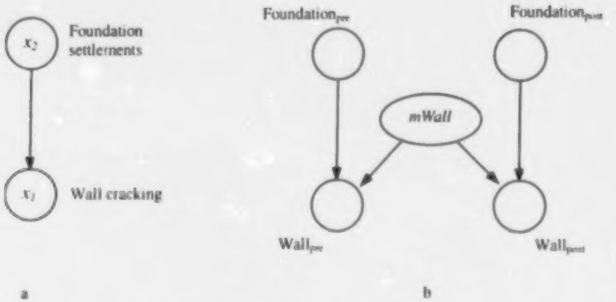


Figure 4: **a) A Bayesian network for the interaction between Foundation settlement and Wall cracking process. b) A persistence network for determining the probability of Wall cracking after we consolidate foundation system, given that the Wall cracking is currently active.**

As shown in Table 1, the mapping node 'm_{Wall}' has two possible states: 1) 'relevant', where the Wall cracking is active if the Foundation settlement is 'high'; 2) 'not relevant' where the Wall cracking is active regardless of condition of Foundation settlement.

Table 1: **The possible mappings between 'Foundation settlement' and 'Wall cracking'.**

	Relevant		*Not relevant*	
Foundation settlement	Low	High	Low	High
Wall cracking	Inactive	Active	Active	Active

In this model the causal relationship between domain nodes are deterministic. For example, if 'Foundation settlement$_{pre}$' is 'high' and 'm_{Wall}'is 'relevant', then 'Wall cracking$_{pre}$' will be 'Active'. The uncertainty in the relationship between 'Foundation settlement' and 'Wall cracking' is encoded in the probabilities for the node 'm_{Wall}'.

By using a single node 'm_{Wall}' to represent the mappings between 'Foundation settlement' and 'Wall cracking' both before and after the action is taken, we encode the assertion that the mapping (or mechanism) between cause and effect is not affected by actions that may change the cause. We could equivalently have two mapping nodes, one for before and one for after the action, with an arc between the two.

In order to calculate the probability that the wall cracking will be inactive after consolidating the foundation, we set 'Foundation settlement$_{post}$' to state 'low' and set 'Wall cracking$_{pre}$' to state 'active' in the network in Figure 4b. We then apply a standard belief network inference algorithm to the network to calculate the probability that 'Wall cracking$_{post}$ = inactive'. In general, suppose we have a Bayesian network for a set of domain variables $X \equiv \{x_1, x_2, \ldots, x_n\}$; then suppose that we want to answer questions of the form: 'What would be the probability of $X^{*} \subseteq X$ if we were to take some action, given that we now observe $Y \subseteq X$. To answer such questions, we construct a Bayesian network as we did in our example. First, we copy the network, using the first and second instances of the network to represent the domain variables before and after we take the action. Second, we introduce mapping nodes 'm_i' for each domain node 'x_i' and assess the prior probabilities of these nodes. Typically, these mapping nodes will be mutually independent, but they need not be (Heckerman and Shachter, 1995). Third, we make both versions of node x_i the same deterministic function of its parents and m_i. Finally, we identify those domain nodes in the post-action network that are affected directly by our action, break the arcs from their parents, and set the states of these nodes to their values as determined by our action. Under this construction, as in our example, the shared mapping nodes encode causal persistence. We refer to Bayesian networks constructed in this manner as persistence networks. An extension of persistence networks with probabilistic account of actions is known under the name of influence networks (Heckerman and Shachter, 1995).

In figure 5 is shown the persistence network of the wall cracking rehabilitation problem. The persistence network is a compound of three parts: the first bounded by the dashed fence is the static primitive bayesian network; the second part, in which nodes have the suffix 'postF', is related to the action of consolidating the foundation system and the third, in which nodes have suffix 'postC', is related to the operation of making a fastener beam on the upper side of the wall. Note that, in each part of the network, there is only the copy of domain nodes directly affected by the action performed, reflecting the assertion that the actions influence exclusively one component besides the cracking process. The model in the figure allows us to compute for example the probability that the wall cracking will be halted after the consolidation of foundation system (Wall cracking$_{postF}$ = inactive). In this case the nodes directly updated by the user are those shaded.

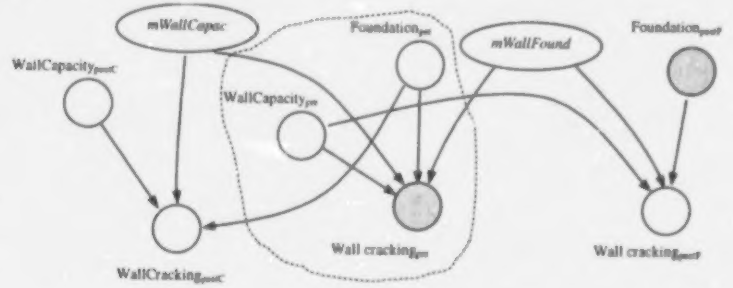


Figure 5: **Persistence network of the wall cracking rehabilitation problem**

5 Conclusions

We have discussed a decision-theoretic framework to support planning management of rehabilitation of building components. Particular attention has been focused to the capability of model to respond to the information updating about building state, which is modified during the rehabilitation process. The model presented here is being implemented into an automated assistant. Moreover we are working to specialize a version of the system in the particular field of structural rehabilitation.

6 References

Breese, J., Horvitz, E., Peot, M., Gay, R., and Quentin, G. (1992) Automated decision-analytic diagnosis of thermal performance in gas turbines. In *Proceedings of the Inter- national Gas Turbine and Aeroengine Congress and Exposition*, Cologne, Germany, American Society of Mechanical Engineers.

Colajanni, B., De Grassi, M., Di Manzo, M., Naticchia, B., (1991) Can planning be a research paradigm in architectural design?, in *Proceedings of First International Conference on Artificial Intelligence in Design*, Edimburgh. Scotland.

de Kleer, J. and Williams, B. (1987) Diagnosing multiple faults. *Artificial Intelligence*, Vol. 32. pp. 97-130.

Genesereth, M. (1984) The use of design descriptions in automated diagnosis. *Artificial Intelligence*, Vol. 24. pp. 311-319.

Heckerman, D., Horvitz, E., and Nathwani, B. (1992) Toward normative expert systems. Part I: The Pathfinder project. *Methods of Information in Medicine*, Vol. 31. pp. 90-105.

Heckerman, D., Breese, J., and Rommelse, K. (1994) Sequential troubleshooting under uncertainty. In *Proceedings of Fifth International Workshop on Principles of Diagnosis*, New Paltz, NY. pp. 121-130.

Heckerman, D., Breese, J., and Rommelse, K. (1995) Decision-theoretic troubleshooting. *Communications of the ACM*, Vol. 38. pp.49-57.

Heckerman, D., and Shachter, R. (1995). Decision-theoretic foundations for causal reasoning. *Journal of Artificial Intelligence Research*, Vol. 3, pp. 405-430.

Heckerman, D., and Breese, J. (1996) Decision-Theoretic troubleshooting: a framework for repair and experiment, *Technical Report MSR-TR-96-06*, Microsoft.

Jensen, F.V. (1996) *An Introduction to Bayesian Networks*. Springer, New York.

Kalagnanam, J., and Henrion, M. (1990) In Shachter, R., Levitt, T., Kanal, L., and Lemmer, J., editors, *Uncertainty in Artificial Intelligence 4*, pp. 271-281. North-Holland, New York, 1990.

Pearl, J. (1988) *Probabilistic Reasoning in Intelligence Systems*. Morgan Kaufmann, San Mateo, CA.

Pearl, J. (1996) Causation, action, and counterfactuals. In Y. Shoham, editor, *Theoretical Aspects of Rationality and Knowledge, Proceedings of the Sixth Conference*, pp. 51-73. Morgan Kaufmann, San Francisco, CA.

Shachter, R. D. (1990) Special issue on influence diagrams. Networks: *An International Journal*, Vol. 20 (5).

Spirtes, P., Glymour, C., and Schienes, R., (1993) *Causation, Prediction, and Search*. Springer-Verlag, New York.

Srinvas, S. and Horvitz E., (1995) Exploiting System Hierarchy to Compute Repair Plans in Probabilistic Model-Based Diagnosis. *Technical Report MSR-TR-95-28*, Microsoft.

150 A TOOL FOR BUILDING REFURBISHMENT AND ITS APPLICATION

M. Fiori and S. Croce

Politecnico di Milano, Italy

Abstract

The paper reports the results of the application of an analysis tool designed to support the optimisation of building refurbishment projects.

The analysis process goes through many evaluation phases, starting from the assessment of economical feasibility to the technical evaluation of the layout and the performances of the buildings and its components, and it is based on the survey of the starting conditions and the systematic definition of a briefing set of goals, based on performance approach
The analysis is based on a first identification of a set of performance lacks and faults of the building system, as to define the goals of the refurbishment project.

Once these objectives are established, a set of refurbishment strategy is extracted from a database in which every kind of possible refurbishment strategy is collected. This is the set of all the possible refurbishment strategies able to solve identified problems i.e. to reach established objectives.
A first compatibility analysis is then practised in order to exclude every strategy that is not economically or technically feasible with clear evidence. Once this second selection is made, then, detailed refurbishment solutions are analysed, in order to optimise costs, durability, maintainability and every other stated objective

This methodology has been validated with a first application to the case of mass housing refurbishment projects of some precast panel buildings in Milano. These building are strongly characterised either from the point of views of their typology and technology. This determines a reduction of the number of possible refurbishment solutions.

Keywords: refurbishment; methodology; performance approach; precast concrete panels

Durability of Building Materials and Components 8 (Volume Three). *Edited by M.A. Lacasse and D.J. Vanier*. Published in 1999 by NRC Research Press, Ottawa ON K1A 0R6, Canada. ISBN 0-660-17742-0

1 General principles

The main goal of this methodology is supplying tools for building refurbishment and paying attention to technology.

Refurbishment does not mean the return of initial project condition (time zero of service life): this word refers to improvement of environmental condition of building starting from a situation of degeneracy.

The purpose of the project is increasing quality of buildings in order to set the same level we usually request in construction.

This methodology gives the possibility of identifing the most correct technological solution for the main part of construction and arriving to an acceptable level of quality at the end.

The first step of such methodology is analysing the typical parameters of building in the present condition and making a comparison between them and those we are looking for in the project.

By using financial analysis based on a few parameters linked to building degradation, it is also possible to estimate the feasibility of building refurbishment.

It is incorrect to identify this methodology with a data base of possible solutions for building problems; on the contrary, it is aimed at organising a system of solutions: strategies in use, discover possible connections and compatibility between different solutions.

That means that every solution becomes part of a system in which they are directly linked one to each other. The final result is an improved product.

In order to solve a problem, in fact, there are lots of solutions in competition one to each other as regards technological and environmental compatibility (they could improve some performance or worses others).

In some other cases particular solutions could permit the use of new products and increment the technological quality of whole the building.

This methodology of project is based on performance approach: all analysis, included those linked to dimensioning of buildings units, are based and organised on subtraction of project performance from the initial condition.

2 General structure

This method is composed of different steps: every one has its particular goal:

1) financial feasibility;
2) analysis of space;
3) survey of damaged parts of building;
4) environmental analysis;
5) analysis of technological parameters and pathological cases;
6) energetically analysis;
7) analysis of building systems;
8) implementation of strategies and system verification;
9) technological solutions.

3 Comparison between building re-use, building demolition and new building construction: analysis of financial feasibility.

First of all, for important projects, it is necessary to identify this step by paying attention on the two choices:

1) re-use of building;
2) demolition and new construction.

It is important that such analysis is one of the first steps, in order to avoid waste of time and money (ex. surveys) in case of demolition.

Comparison between the two choices depends on the value of property after a correct re-use or a new construction.

This analysis is obtained using typical processes of building estimation.

Following estimation criteria based on this comparison process, it is possible to organise the most suitable financial plan.

Three different suppositions are the usual hypothesis:

1) building retraining or re-use is chosen for financial convenience;
2) demolition and new construction are chosen for financial convenience;
3) the above choices have the same financial convenience: the last decision should be taken considering social, political and cultural environment.

4 Space organisation analysis

The first step in this stage is based on the identification of the characteristics of building in the present condition (restraining time zero; t_{RO}).

The essential information we need to collect in a data base, regards, for example, typology of building.

That information should be collected with the official set of rules that identifies space restraints.

At this time method gives the opportunity to modify building space organisation by considering three variables: typology, morphology of flats and number of people living in them.

Next step is to point at space units which are not correct in dimension (i.e. surface is not enough).

At the end of this process it is possible to understand if it is necessary to modify space organisation.

After this stage a decision on demolition operation could be taken.

5 Survey of damaged parts of building.

The survey of geometry, decay and obsolescence is important for the knowledge of building present configuration, and is also fundamental to start the following steps in performance method.

The survey of building geometry is necessary even if original project (plans, prospects, sections, certificates of construction systems) is available, because of the real construction being not a perfect copy of the project.

The survey of decay obtained with specific instruments gives the opportunity to verify if a component of the building is "out of order".

All results are organised in a "system": the most correct strategy of operation depends on the different decay problems and could be different when dealing for example with roof or external wall or with energy problems.

Last but not least the survey of obsolescence should discover all those situations which were correct at the beginning of the service life of building, but which are now wrong because of changing in life standard and rules (e.g.: electrical components).

6 Environmental analysis

The analysis of environmental requests gives the possibility to identify strategies for this kind of performance deficit.

Environmental parameters could be defined starting from the typical way of using building.

Hereby we enclose a typical list of environmental parameters for residence:

- living temperature in winter
- number of winter air exchange
- asymmetrical radiation in summer
- thermal inertia of building components
- speed of cooling
- daylight factor

The general system is based on comparison between environmental performance of the project and the present condition.

Next step is the evaluation of environmental performance of the project.

It is necessary to create a unification of performance request for space units even if activities are different, by looking at the most restrictive values.

This logical process is based on comparison, for each performance, between the new project value and the present one.

The most correct strategies depend from presence or absence of deficit.

In case of no deficit the process indicates the most proper strategies, considering technological and financial opportunities.

The right solution is always linked to the opportunity of working on technical components that already need to be corrected.

7 Analyse of technological parameters and pathology

Strategies for resolution of performance deficits of building components are pointed out using a particular "atlas of strategies", one for each part of the building. Input data are collected from the comparison between the value of project performance (from literature) and the value of present building performance.

The presence of pathology is deducted by mathematical logic by using two possible data:

1) instantaneous performance loss
2) gradual performance loss.

The first case is connected to pathologies which already exist. The second case is define using the "atlas of strategies": the above method comparison gives important information for the right solution of the problem.

Pathology is a dynamic phenomena and so it is necessary to the exactly describe actual condition: starting from this description it is possible to work on building components just on their surface or by making important changes.

Each performance deficit or pathology may be sharing solution strategies with some other pathology.

For this reason it is definitely necessary to identify which is the prevailing one. This choice allow to identify the most suitable strategy for each group of performance deficit.

8 Implementation of strategies and system verifications

The implementation of other technologies, obtained with a slow cost, could be the consequence of a process based on technological strategies divided for each part of the building.

Such new technologies improve the technological quality of the whole building.

Moreover they become part of the "building system", with economical advantages that would not be obtained in single works.

This goal identifies a new important stage in the methodological process. Strategies of single part of the building are compared with global strategies: congruencies are verified, global strategies are activated. For example global strategies concern passive solar systems or ventilation.

Table 1: Example for strategies for wall

STRATEGY	Radiation control	Airborne noise insulation	Thermal insulation	Luminance passage	Luminance control	Imperviousness to water	Imperviousness to air	Air passage control	Insect passage defence	Infiltration between casing and shoulder	Casing corrosion	Casing deformation
Spandrel demolition and casing replacement		x	x	x		x	x			x	x	x
Fixture and casing replacement		x	x			x	x			x	x	x
Replacement fixture only		x	x			x	x					x
Glass replacement		x	x									
Strip replacement						x	x					
Increase of the thermal insulation of the screening system			x									
Insertion of internal thermal insulation elements			x									
Increase of window sill reflectance				x								
Insert outdoor shelf				x								
Insert lateral metallic carter										x		
Sealing				x								
Insert fly screen									x			
Technical equipment for ventilation control								x				
Insert shading devices					x							
Fixture painting											x	
Insert orizontal brise-soleil	x											

9 Data base of technological solutions

A database of technologies, connected with strategies, has been organised in the research.

In this database all strategies are linked to a list of typological solutions, directly obtained from performance requests: for each performance we indicate the typical parameters (materials, width and so on).

Each performance is divided into differents groups and each group is linked to a specified solution that is defined by evaluating the previous parameters.
Indicators of costs, management of the process and management of components during building service life also identify technological solutions.

If different technological solutions can be used, such indicators give the right suggestion.

For each solution we enclose some rules to consider for a correct installation of building components.

10 Conclusion

This process was elaborated starting from a data base collected studying big districts of public housing. This fact does not mean it has a unique destination: it can be surely applied to other refurbishment cases.

One of the goals of this method is also to guarantee the control of project situation by the planner giving him continuous information and help on line.

All solutions are part of a logic system and every time that logic must bie clear to the designer and, if necessary, it can be changed by him.

Anyway the last official decision on technological solution is given by the planner and not by the computer.

In fact the process is not independent from the planner decisions. The database of technological solution will be expanded starting from planner experience and knowledge.

11 References

Croce S., Daniotti B., De Angelis E., Filiberti A., Fiori M., Tiso A., (1996). From comfort requirements to building elements design: a performance approach based design training method for building engineers. *International conference CIB-ASTM-ISO-RILEM Application of the Performence Concept in Building*, Tel-Aviv, Israel.

Borlenghi R., Fiori M., Pavesi A., Poli T., Trivelli A., (1998). *Rehabilitation Methods for Residential Buildings*. IASBE, Berlin.

Croce S., Pizzi E., Fiori M., Trivelli A.,(1998). Diagnosis y estrategias de réparacion para la recalificatión de las edificiones: un caso de estudio. *IV Congresso iberoamericano de patologia das costruçoes*, Porto Alegre, Brasil.

Croce S., (1994). Prevention of defect in building. *International CIB Symposium Dealing with defects in building*, Varenna, Italy.

Croce S., (1993). facade pathologies in modern architecture. *Congresso iberoamericano de patologia das costruçoes*, Barquisimeto, Venezuela.

151 PC/GIS BASED SYSTEM FOR MAINTENANCE MANAGEMENT OF WOODEN BUILDINGS — MMWOOD

S.E. Haagenrud, B. Eriksson, C. Sjöström, and T. Skancke
Norwegian Building Research Institute, Oslo, Norway

Abstract

The EU-project ENV4-CT95-0110 Wood Assess pursued pooling of European resources to develop methods and technologies for proper assessment of the conservation state, and for mapping and assessing environmental risk factors to wooden cultural buildings. The project completed all its tasks and achieved all its objectives, developing and validating a Condition Assessment Protocol, methods for continuous measurements of moisture and temperature in the micro-environment, and systems for mapping environmental risk factors to wooden cultural buildings. The theoretical and methodological foundation for the project builds heavily on the internationally recognised methodology for prediction of durability, service life and maintenance intervals, now being standardised by the ISO/TC59/SC14 "Design Life". European standards like prEN 13013-3 "Calculation of driving rain index for vertical surfaces from hourly wind and rain data" have been used in estimating environmental exposure and it's impacts on the building objects. The PC based pilot version of the Assessment Protocol is available on a Geographical Information System (GIS) platform that can store, integrate and further process data of all kind such as text, pictures, maps, etc. Implementation of such a system puts requirements on its users, and it will require maintenance, support and further development to adopt to new technology and knowledge. These issues are dealt with in the following up project, the ENV4-CT98-0796 "System for Maintenance Management of Historic (Wooden) buildings", where the Wood-Assess concept is further developed towards the market.

Keywords: condition assessment, maintenance management, durability, service life, environmental risk factor mapping, Geographical information systems.

Durability of Building Materials and Components 8 (Volume Three). *Edited by M.A. Lacasse and D.J. Vanier*. Published in 1999 by NRC Research Press, Ottawa ON K1A 0R6, Canada. ISBN 0-660-17742-0

1 Introduction

Europe's rich culture in wooden buildings is rapidly degrading due to environmental impact, improper conservation techniques, and lack of resources and technological tools for appropriate conservation.

The recently finalised EU-project ENV4-CT95-0110 Wood Assess pursued pooling of European resources to develop methods and technologies for proper assessment of the conservation state, and for mapping and assessing environmental risk factors to wooden cultural buildings (Haagenrud et al, 1998). The project completed all its tasks and achieved all its objectives. During the pilot testing of the applications small and medium sized companies (SMEs) and clients expressed great interest and need for potential product developed from the Wood-Assess concept, and in a new EU sponsored project, ENV4-CT98-0796 MMWood "System for Maintenance Management of Historic (Wooden) buildings"(acronym MMWood), the Wood-Assess concept is further developed towards the market.

2 Wood-Assess - objectives and strategies

Objectives of this project were to develop and validate:

1. Systems and methods for assessing the conservation state for the outer wooden parts of cultural buildings, and their causes and effects.
2. Methods for measuring continuous surface time of wetness and resulting moisture content inside wood, biological and environmental damage to wood.
3. Methods for assessing and mapping environmental risk factors and areas for wood on meso- and micro- scale at some locations in Europe.

The systems and methods have been validated by assessing outer wooden parts of chosen buildings in Germany, Poland, Norway, and Sweden.

3 Project methodology and relation to ISO/TC59/SC14"Service Life Planning"

3.1 Basic elements of Service Life Prediction

The Wood-Assess project develops methods and technologies that will enable prediction of service life and maintenance intervals for buildings, relying upon the methodological way to predict service lives for building materials and components, now subject to standardisation in the ISO/TC59/SC14 "Design Life" (ISO/DIS 15686-1 1997; ISO/CD 15686-2 1998).

This standardised methodology encompasses prediction models, that rely on knowledge of performance-over-time functions (P-T), degradation mechanisms, dose-response functions and environmental exposure data. Inspection and condition assessment of buildings, which is a main aim of Wood-Assess project, is defined as a major long-term test method for gathering test data in the PSL method.

In practice the service life and maintenance intervals are dependent on many factors. The so-called factor method in the ISO draft standard (ISO/CD 15686-1 1997) lists the following modifying factors to account for when assessing the service life and maintenance intervals of a specific building:

$$\mathrm{ESL} = \mathrm{RSL} \times A \times B \times C \times D \times E \times F \qquad (1)$$

Where: *ESL = estimated service life*
RSL = reference service life
and the modifying factors A-F are described in Table 1.

Table 1: Modifying factors of "the factor method" (ISO/DIS 15686-1 1997).

Factors related to inherent quality characteristics	A_1	Performance of Materials	Material type or grade. Manufacture, storage, transport
	A_2		Durability features. Protection system
	B	Design level	Details of construction: Joints fixing, incorporation, sheltering by rest of the structure
	C	Work execution level	Site work: Quality to standard or manufactures specifications. Level of workmanship, climatic conditions during execution work
Environment	D_i	Indoor environment conditions	Condensation, aggressiveness of environment, ventilation
	D_o	Outdoor environment conditions	Macro, meso, micro environment conditions
Operation conditions	E	In use conditions	Mechanical impact, category of users, wear and tear, vandalism
	F	Maintenance	Quality and frequency of maintenance, accessibility for maintenance

3.2 Degradation model and damage function for wood

The degradation of outer parts of wooden buildings are influenced by a whole set of factors (see Figure 1) such as environmental degradation agents classified here according to ISO 6241 (ISO 6241 1984) quality of wood and the type of and quality of wood, protective treatment, maintenance and so on.

The relationship between the environmental degradation agents and the observed effects are expressed as dose-response functions. If performance requirements and their limit states are included into the function it transforms into a *damage* function. Due to the very complicated nature of the degradation system and a lack of systematic scientific research, very few quantitative dose-response functions exist today. Scheffer's Climatic Risk Index (SCRI),

$$SCRI = \frac{\sum_{Jan}^{Dec}\left[(T-2)(D-3)\right]}{17} \qquad (2)$$

that describes the rotting tendency of wood as a function of climatic parameters of temperature and moisture, is an example of a damage function for wood (Scheffer, 1971). A main objective of the project was to develop and validate such an index for the chosen locations.

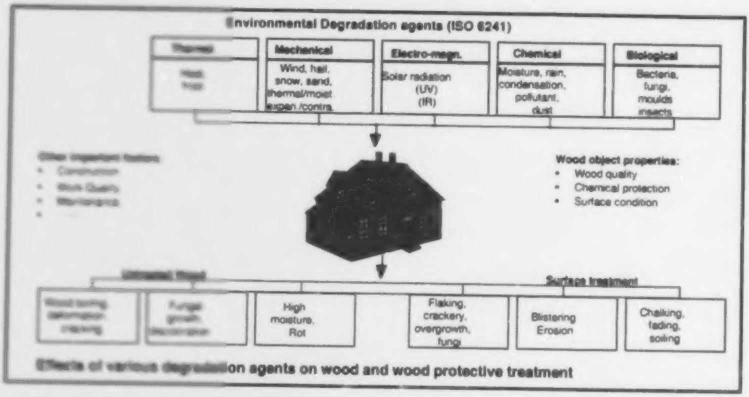

Environmental Degradation agents (ISO 6241)
Thermal
Heat, frost
Mechanical
Wind, hail, snow, sand, thermal/moist expan./contra.
Electro-magn.
Solar radiation (UV) (IR)
Chemical
Moisture, rain, condensation, pollutant, dust
Biological
Bacteria, fungi, moulds insects
Other important factors:
Construction
Work Quality
Maintenance
Wood object properties:
Wood quality
Chemical protection
Surface condition
Untreated Wood
Surface treatment
Wood boring, deformation, cracking
Fungal growth, discoloration
High moisture, Rot
Flaking, crackery, overgrowth, fungi
Blistering Erosion
Chalking, fading, soiling
Effects of various degradation agents on wood and wood protective treatment

Fig. 1: Degradation of wooden objects – model of degradation factors and their observed effects

To be active the fungi involved need sufficient water and the right temperature over time. The water needed will vary from fungus to fungus. While white rot needs as much as 30% water in the wood to develop, dry rot needs only 23%. It is very limited knowledge on required time for fungi attack to develop, taking that the temperature-moisture conditions are favourable. For this type of studies techniques for simultaneous measurements of temperature, moisture and time are important. In the Wood-Assess project, a NILU designed instrument, WETCORR, was used for such measurements in the micro-environment (Eriksson *et al.* 1998).

Furthermore, when looking at building elements and the whole building, factors such as constructive solutions, micro environment at the building, workmanship and the time aspect, i.e. the history of the building becomes essential.

Information on all these elements needs to be elaborated in a systematic way as does the methodology for carrying out the condition assessment survey including the field inspection.

4 Results

4.1 PC based assessment protocol and field inspection system

The Assessment protocol is synthesised from existing national guidelines and standards in the participating countries (Veit *et al* 1998). The protocol is available in a PC-based geographical information system (GIS) as depicted schematically in Figures 2 and 3 below. Figure 2 shows a schematic view of the levels of information and information elements in GISWood, such as:

- Building orientation system;
- Description of purposes, phases and levels of investigation;
- Overview of investigation and measuring methods;
- Themes for environmental risk factors;
- Databases with types, degrees, causes and effects of damages (Pictures and texts); The condition degrees are classified on a scale 0 (no symptoms), 1 (slight symptoms), 2 (medium-strong symptoms) to 3 (strong symptoms including malfunction and collapse)
- System for graphical mapping of damages.

This system will give the user a tool to handle and systematise data from the assessment of cultural wooden buildings. This ranges from needed basic background data and knowledge down to detailed measurement and inspection data. Different user levels are taken into account (Veit *et al* 1998)

The Wood-Assess–GIS system was based on the standard ArcView 2.1 package, which is a part of the ARC/INFO GIS system, delivered by ESRI. ArcView is a Windows based program running under MS-Windows 3.1, Windows 95 and Windows NT.

Figure 3 shows the assessment and categorisation of some damages at Hjeltarstua, Maihaugen, Norway as recorded by the inspection system, MMWood and exhibited in the GISWood system. MMWood is a computer-based system developed to structure the work and the resulting information handling from inspections, and also as a tool easing the planning and execution of maintenance work.

The inspection is done by using a hand-held computer with a bar-code reader and a digital camera for taking pictures. The bar-codes are defined in the assessment protocol and consist of categories of elements of a wooden building, observations of symptoms linked to these elements, and a set of predefined questions ensuring the proper registration of relevant information.

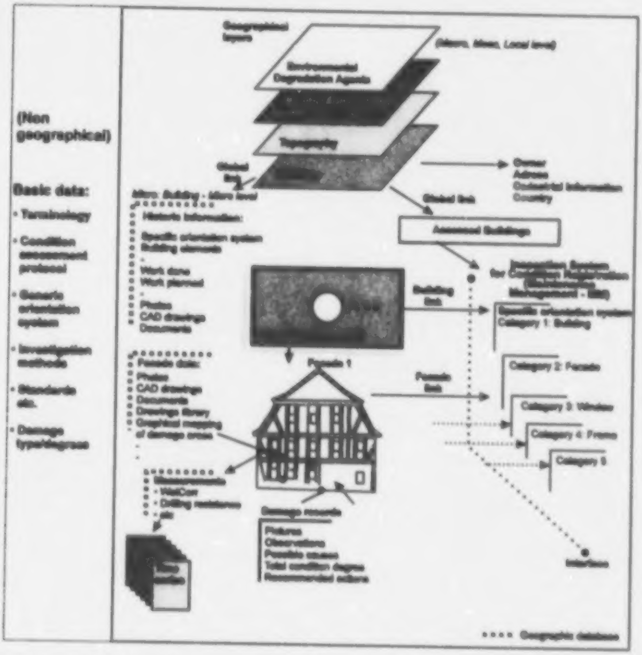

Geographical layers
(Macro, Meso, Local level)
Environmental Degradation Agents
Topography
Global link
Micro: Building - Micro level
Owner
Adress
Cadastral information
Country
Global link
Assessed Buildings
(Non geographical)
Basic data:
• Terminology
• Condition assessment protocol
• Generic orientation system
• Investigation methods
• Standards etc.
• Damage type/degrees
Historic information:
Specific orientation system
Building elements
Work done
Work planned
Photos
CAD drawings
Documents
Inspection System for Condition Registration (Maintenance Management - ISM)
Building link
Specific orientation system
Category 1: Building
Facade 1
Facade data:
Photos
CAD drawings
Documents
Drawings library
Graphical mapping of damage areas
Facade link
Category 2: Facade
Category 3: Window
Category 4: Frame
Category 5
Measurements
• WetCorr
• Drilling resistance
• etc
Damage records
Pictures
Observations
Possible causes
Total condition degree
Recommended actions
Interface
Geographic database

Fig. 2: Schematic view of integration of information and information elements in GISWood

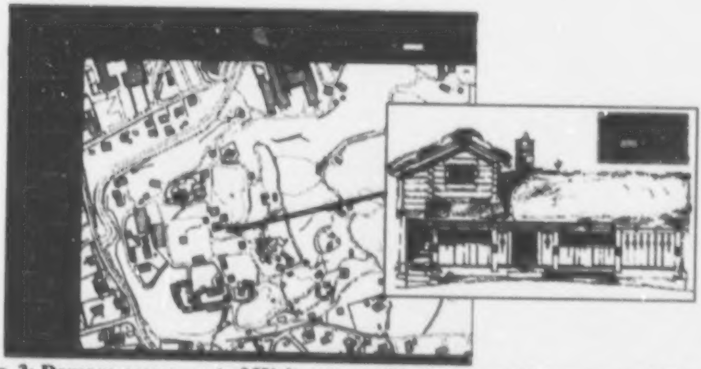


Fig. 3: Damage assessment of Hjeltarstua at Maihaugen, Lillehammer exhibited in GISWood

4.2 Characterisation and mapping environmental risk factors from regional to local and micro- scale — use of prEN13013

As there are great differences in temperatures and precipitation regimes in Europe, there are likewsie to be expected great differences in potential rates of wood decay. This is in accordance with the encountered practice. For the interpretation of the damage observed on building objects data is needed on levels and spatial variations of environmental degradation factors on various geographical scales (EOTA, 1997). One frequently used classification of geographical scales for climate and environment is the division into macro, regional, local and micro, as shown in Figure 4.

For the characterisation and mapping of environmental degradation factors to the regional scale, data must be provided from *existing data sources* due to the cost and the time span otherwise involved. Fortunately, a lot of environmental data on macro/regional scale is available from meteorological and environmental research communities. However, for use on the local and micro scale a correlation between this kind of data and the local and micro environment at the building must be done.

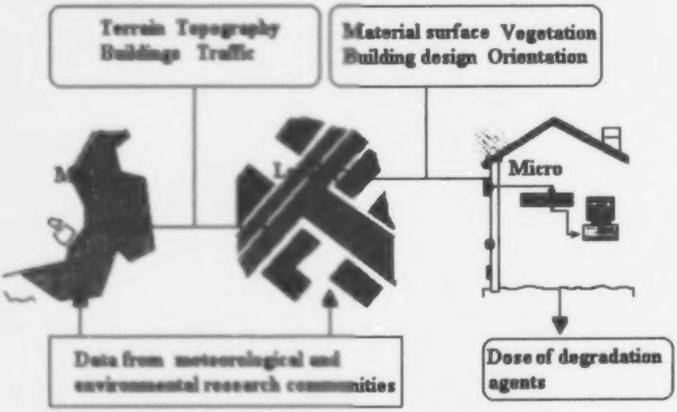

Terrain Topography
Buildings Traffic
Material surface Vegetation
Building design Orientation
M
L
Micro
Data from meteorological and environmental research communities
Dose of degradation agents

Fig. 4: Exposure environment on different geographical scales, and modifying factors to consider when transforming environmental data from the regional level to local and micro level. (Noren *et al.* 1998)

The Wood-Assess methodology for assessing and mapping environmental risk factors and areas is based on assessing both Scheffer's CRI for potential wood decay and also the potential of a WETCORR based CRI for the micro-environmental conditions. It is shown that yearly and monthly SCRI can be calculated and mapped by use of available meteorological data for temperature and precipitation from a very extensive network of stations in the participating countries. These calculations are made available in the GISWood application, as shown in Fig. 5.

Regression analysis shows that in this case the meteorological site represents to a reasonable degree the conditions at the object site. This is not always the case and specific assessments need to be carried out in each case (ISO /DIS 15686-1 1997).

In order to increase the spatial resolution and thus the reliability of risk factor assessment, the temperature and precipitation can be modelled on the *regional* and *local* level taking into account the effects of topography and sunny and shaded areas. A digital terrain model in GRID/ArcInfo has been developed to give a good description of SCRI on a regional and local scale based on available meteorological data. Figure 6 shows the local scale modelling of SCRI in the Lillehammer/Maihaugen area.

Digital maps with models of precipitation, temperature and relative humidity can probably also be obtained from the national meteorological offices in many countries and form a proper basis for more detailed modelling of SCRI.

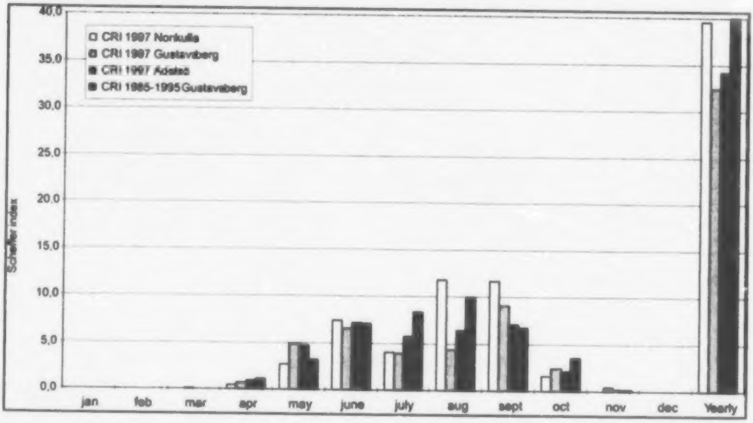


Fig. 5: Calculated monthly and yearly Scheffer´s climatic risk index at Norrkulla gård and the meteorological sites Gustavsberg and Adelsö

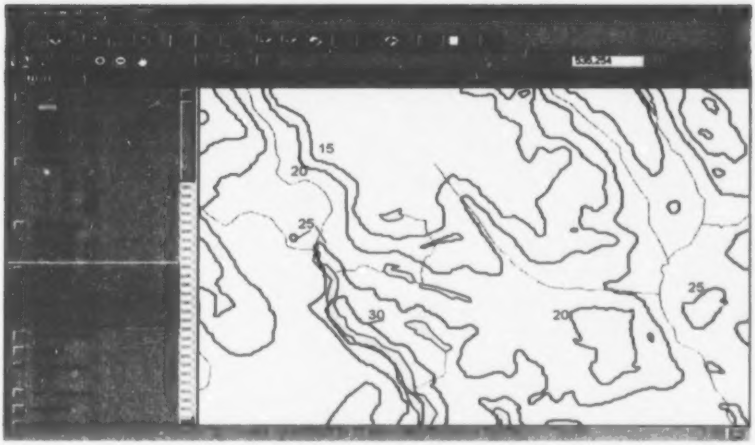


Fig. 6: A smaller section of the Iso-line map of the average Scheffer's index in the area around the test site Maihaugen

A new attempt for using available regional meteorological data to assess microclimatic impact on buildings has recently been proposed in the prEN 13013-3 "Calculation of driving rain index for vertical surfaces from hourly wind and rain data." (CEN 1997). This is mainly based on the British standard BS 8104:1992 "Code of practice for assessing exposure of walls to wind-driven rain." (British Standard 1992). This standard, that addresses the impact of driving rain on masonry, can be used in the same conceptual way to assess the impact on the porous material wood. In mapping the environmental risk factors and areas we have therefore applied this standard on facades where the wetness impact is recorded with the WETCORR instrument.

The prEN specifies a procedure for analysing the hourly rainfall and wind data derived from meteorological observations so as to provide an estimate of the quantity of water likely to impact on a wall of any given orientation. It takes account of topography, local sheltering and the type of building and wall.

After calculating the driving rain spell index, I_S, for a period of time the next step is to estimate the actual buildings location and exposure compared to an airfield. That is performed by estimating the values of four different parameters, the roughness coefficient, C_R, the topography coefficient, C_T, an obstruction factor, O, and a wall factor, W, and converting the airfield indices into wall indices, I_{WS}, by the formula:

$$I_{WS} = I_S \times C_R \times C_T \times O \times W \quad (3)$$

The prEN has also categorised, described and illustrated the C_R, C_T, O and W factors.

Table 2: Estimated values for the roughness coefficient, C_R, the topography coefficient, C_T, the obstruction factor, O, and the wall factor, W

	Factor	Hjeltarstua	Alte Mangel	Berggrenska	Norrkulla
South wall	C_R	0.75	0.75	0.75	1.15
	C_T	1.0	1.0	1.0	1.0
	W	0.4	0.4	0.3	0.3
	O	0.4	0.4	0.6	1.0
East wall	C_R	0.75	0.75	0.75	1.15
	C_T	0.8	1.0	1.0	1.0
	W	0.4	0.3	0.3	0.2
	O	0.5	0.5	0.2	1.0
North wall	C_R	0.75	0.75	0.75	1.15
	C_T	1.0	1.0	1.0	1.0
	W	0.4	0.4	0.3	0.3
	O	0.3	0.3	0.2 lower part 0.4 higher part	0.5
West wall	C_R	0.75	0.75	0.75	1.15
	C_T	0.8	1.0	1.0	1.0
	W	0.3	0.3	0.3	0.2 lower part 0.3 higher part
	O	1.0	0.4	0.2	1.0

The WETCORR technique allows for simultaneous monitoring of the surface temperature/wetness and the resulting temperature profile inside wood by the surface sensor and the INWOOD sensor respectively. Thus two WETCORR based indexes has been proposed, namely the WC-CRI for the surface rotting susceptibility, and the IW-CRI for the inside rotting (Henriksen *et al.* 1998). Comparison of the driving-rain calculations according to prEN13013 and using the WETCORR data shows good correlation.

The Wood-Assess concept for assessing environmental impact on to building facades can be directly applied to the Factorial approach in the ISO standard. This provides major new methodologies and tools for assessing the climatic risk factors for wood preservation on meso-, local- and micro scale in Europe.

5 Further developments towards market in new EU project

During the pilot testing of the applications small and medium sized companies (SMEs) and clients expressed great interest and need for potential product developed from the Wood-Assess concept. As the project also got a very high rating from the EU, a new project proposal was developed and endorsed by the EU. In this new project, ENV4-CT98-0796 MMWood "System for Maintenance Management of Historic (Wooden) buildings"(acronym MMWood), the Wood-Assess concept is further developed towards the market.

The major needs expressed by these actors were a broader spectre of materials, an updated and fully integrated technology platform and inclusion also of the maintenance management phase. The new project that started in January 1999 runs for two years; therefore comprise the following main tasks:

To *develop* and *validate* for the SMEs an integrated Maintenance Management system for historic (wooden) buildings adapted to the needs and purposes of various user group levels. Based on the *Wood-Assess concept and results* the modular GIS (Geographic Information System) based system, MMWood, shall specifically contain:

- a documentation system for outer and inner parts of historic buildings and components (wood, stone, brick and rendering)
- soft- and hardware tools for building inspection for maintenance tasks,
- an environmental risk factor assessment module,
- a standardised maintenance assessment module based on complementation of the Wood-Assess process of assessing the symptoms, causes, effects, consequences, risks and remedial actions for environmental damages to the historic buildings, and
- a cost and maintenance planning module.

There are three SMEs (Germany, Sweden, Norway) and seven R&D partners (Norway, Sweden, Germany, Italy and Latvia) collaborating. The beta version of the application will be developed during the first year, installed with clients and test objects for validation in year two.

Implementation of such a system puts requirements on marketing, selling, its users, and requires maintenance, support and further development to adopt to new technology and knowledge. These issues are being delt with in Collaborative Agreements.

6 Conclusions from Wood-Assess

The Wood-Assess project has completed all its tasks and achieved all its objectives, developing and validating an Assessment Protocol, methods for continuous measurements of moisture and temperature in the micro-environment, and systems for mapping environmental risk factors to wooden cultural buildings. The total concept is available on a PC -based Geographical Information System (GIS) platform.

The theoretical and methodological foundation for the project builds heavily on the internationally recognised methodology for prediction of durability, service life and maintenance intervals, which is now subject to standardisation by the ISO/TC59/SC14 "Service Life Planning".

The Wood-Assess concept for assessing environmental impact on to building facades can be directly applied to the Factorial approach in the ISO standard. This provides major new methodologies and tools for assessing the climatic risk factors for wood preservation on meso-, local- and micro scale in Europe.

Development and implementation of such PC/GIS based Condition Assessment Protocol systems into the field of conservation management of cultural objects represents a new and innovative approach with great exploitation potential.

In a new EU sponsored project, ENV4-CT98-0796 MMWood "System for

Maintenance Management of Historic (Wooden) buildings"(acronym MMWood), the Wood-Assess concept is further developed towards the market.

7 Acknowledgements

The authors are indebted to the Environment and Climate Programme under the European Commission 4th Framework Programme, and the Norwegian Ministry of Environment for funding this research.

8 References

British Standards Institution (1992), "Assessing exposure of walls to wind-driven rain", Code of Practice for assessing exposure of walls to wind-driven rain. (BS 8104:1992).

Eriksson, B., Norberg, P., Haagenrud, S., Henriksen, J. F., Noren, J., Klopfer, R. and Elvedal U. (1998) EU-project ENV4-CT95-0110 Wood-Assess. Project Deliverable no. 7. Final Report WP2: Development and validation of measuring methods. Gävle, KTH (Wood-Assess doc. WP2/Del7/KTH-BMG/1998-08-15).

European Commite for standardization-CEN (1997) Hygrothermal performance of buildings - Climatic data - Part 3: Calculation of driving rain index for vertical surfaces from hourly wind and rain data (prEN 13013-3).

European Organisation for Technical Approvals (1997) Assessment of working life products. PT3 durability. (TB97/24/9.3.1).

Henriksen, J.F., Haagenrud, S.E., Eriksson, B., Norén, J., Klopfer, R., Häusler, J.and Elvedal, U. (1998) EU-project ENV4-CT95-0110 Wood-Assess Project Deliverable no. 8-Final report WP3-Mapping of environmental risk factors on regional, meso and micro scale. Kjeller (Wood-Assess doc. WP3/Del8-/NILU/1998-08-15) (NILU OR 44/98).

Haagenrud, S.E., Veit, J., Eriksson, B., Henriksen, J.F., (1998) EU-project ENV4-CT95-0110 Wood-Assess. Project Deliverable no 5 Final report. Kjeller, Norway (Wood-Assess doc Del5/NILU/1998-08-15) (NILU OR 40/98).

International Organisation for Standardisation (1997) Service Life Planning – Part 2: Service Life prediction Methods. Geneva (ISO/WD 15686-2.2).

International Organisation for Standardisation (1997) Service Life Planning – Part 1: General principles. Geneva (ISO/DIS 15686-1).

International Organisation for Standardisation (1984) Performance standards in building - Principles for their preparation and factors to be considered. Geneva, (ISO 6241-1984).

Norén, J., Westberg, K., Jernberg, P., Haagenrud, S.E., and Sjöström, C. (1998) Service life prediction of buildings and the need for environmental characterisation and mapping. Proc. CIB World Building Congr. Gävle 1998.

Norwegian Standards Association (1995). Condition survey for construction works - Content and execution. Oslo, Norwegian Council for Building Standardization. (Norwegian Standard 3424) (English).

Scheffer, T.C. (1971) A climate index for estimating potential for decay in wood structures above ground. *For. prod. j.*, *21*, 10-25.

Veit, J., Haagenrud, S., Eriksson, B., Henriksen, J. F., Klopfer, R., Krigsvoll, G., Jenssen, K. M., Andreassen, V., Norén, J., Dahlin, E. M., Nilsen, G.B. (1998) EU-project ENV4-CT95-0110 Wood-Assess Project Deliverable no.6 Final report WP1: Development prototype of PC-based assessment protocol. Kjeller (Wood-Assess doc. WP1/Del6/NILU/1998-08-15) (NILU OR 41/98).

152 PREPARATION AND PRIORITIZATION OF MAINTENANCE PROGRAMMES

M.R. Johnson[1] and D.P. Wyatt[2]

[1]Department of the Environment, Transport and the Regions, London,
[2]University of Brighton, UK

Abstract

The maintenance requirements of any asset particularly buildings need a structured process of justification to ensure that funds are available to develop programs to identify preparatory work as well as the timescale for physical execution. Condition appraisals alone will not do this as the operational requirements of the organization using the building need to be assessed as well as the technical needs of the structure and its equipment. A systematic review of maintenance needs will also indicate whether the value of the building warrants the level of expenditure or if there are any potential benefits such as energy savings which could lead to one scheme being given preference over another. Once the value against expense appraisal has been done judgments can be taken using specific criteria such as those affecting safety and operational effectiveness are likely to be of the highest merit. Disruptiveness of the work in progress is a major consideration as it may be desirable to group medium term building maintenance activities in a given building with the most urgent needs. This enables all the disturbing activities to be carried out at the same time. Economies on access, contractor's plant and management costs are possible but the principal purpose of this exercise is to get the building to a state where intrusive maintenance activities are unlikely to recur for several years. Programs need to be reviewed at least annually but this need not involve looking at the whole portfolio. Once the essential framework has been developed it should only be a matter of responding to programmed events as they move towards their date for execution or accommodating unanticipated work.

Keywords: programs, condition appraisals, prioritization, maintenance, operational effectiveness, disruption, serviceability.

Durability of Building Materials and Components 8 (Volume Three). *Edited by M.A. Lacasse and D.J. Vanier*. Published in 1999 by NRC Research Press, Ottawa ON K1A 0R6, Canada. ISBN 0-660-17742-0

1 Introduction

Most building maintenance managers have and prepare works programs for the building for which they are responsible. In some aspects such programs may demonstrate an objective approach in response to the stewardship they are entrusted with and at the same time provide a basis for funding work under consideration and approvals. One of the inherent weakness of such programs are the procedures which are followed mainly to provide cost forecasts or budgets tend to identify work on a largely technical and critical basis.

Condition appraisal can lose credibility if they lack accuracy or flexibility [Smith, 1985]. The causes may be that too broad an approach was used, the system is difficult to use or revise or that the appraisal does not show an appreciation of the needs of the estate as a whole but concentrates on items of work but makes no judgment of how they impinge on the functioning of the building.

Other aspects of the operation of the estate come into play when more important work items have been identified. Economies in future running or energy costs, prevention of cost escalation due to disrepair and savings in management or contract costs by grouping work items together play an important part. Some maintenance operations can be severely disruptive to building users, but may be overcome by grouping a number of schemes together to reduce disturbance to occupiers [Ahonandoy, 1994]. In some cases less urgent work may be carried out before its normally programmed date in order to prevent future disturbance. The needs of the organization using the building will often play a large part in the timing of major work. Work may be delayed because disruption cannot be tolerated at a given time or brought forward to link with the start of new activities in the building or for public relations reasons.

The use of some formally agreed criteria may help to establish links between the base condition of part of a building in need of repair and the urgency of doing the work. Surprisingly condition alone is not always the most important vector. Often legal, safety or operational considerations provide the grounds for the final decision of when and how the repair is carried out. If something is no longer performing satisfactorily and needs occasional running repair but does not create risks of disruption to the activities of the organization occupying the building it is unlikely to attract a high priority for major repair or replacement.

Maintenance programs need to be dependable. The criteria used in maintenance audits after work has been carried out[Robertson, 1983] provide maintenance managers with a good indication of how to defend their proposals.

A programme which can demonstrate that objective criteria have been used will have greater credibility and a better chance of securing funding for its execution. The type of questions an auditor may ask should be considered by the maintenance managers to test the decisions being taken when preparing schedules. They will be better able to justify their actions after the work has been done if it can demonstrated how choices were made in planning the work.

Table 1: Comparison of Maintenance Manager's and Auditors criteria for prioritization

Maintenance manager's criteria	Maintenance auditor's questions
What needs to be done Is it necessary When should it be done	How much has been achieved
Are the right standards being set Is a higher specification justified to give longer service life and/or lower running cost	How good was it
Was the expense justified Could cheaper alternatives provide value over time	How much did it cost
Are appropriate technical, legal and organizational considerations being used to set priorities Should work be linked to other activities either co-incidentally or sequentially	Was the job a priority item

2 Development of maintenance priority systems

In many organizations the priority of general repair tasks is reactive and responds to either breakdowns which appear to be giving the greatest problems or to silence those who complain the loudest. In the right context responsive or breakdown maintenance is an acceptable strategy . There are some items whose failure is not predictable and do not cause great inconvenience whilst waiting to be repaired. When the work is random and low cost it may be cheaper to repair on breakdown than to take preventive action on all similar items some of which may have different rates of failure rendering the preventive strategy uneconomic.

For more substantial maintenance activities a management strategy is imperative. Currently in the United Kingdom there is a number of large estate portfolios in health care, social housings and education. Each of these sectors have had maintenance planning strategies for sometime and since the 1980's have developed system for assessing maintenance priorities. In fact the health sector took the lead in setting down priority factors [Bushell, 1981]. Strategies were developed for council housing and schools and these were reported on by the Audit Commission in the late 1980's.

Early priority factors tended to be descriptive and even when ranked they did not provide a simple means of sorting the work items. Following a review of the UK defense estate maintenance, estate condition reports were required to be supported by a forward maintenance register classified using urgency criteria. [PSA, 1985.a]. The ranking system had four main groupings with a sub-set of deciding factors, usually applied to the two highest classes. (See Table 2 below). A similar system was adapted when a separate defence works administration was set up in 1990 [DWS, 1990].

Table 2: 2 level prioritization system as used for government buildings in the United Kingdom

Class	Level	Description
Main Priority Classifications	Priority 1	UNAVOIDABLE SERVICES: Schemes which cannot be deferred without breaching statutory obligations, health and safety or seriously affecting occupier's operations and functions.
	Priority 2	ESSENTIAL SERVICES: Schemes which cannot be deferred without serious penalties such as damage to property or increased costs.
	Priority 3	URGENT SERVICES: Schemes which are highly desirable to maintain the value and utility of the estate.
	Priority 4	DESIRABLE SERVICES: Schemes which are necessary to maintain property standards or which would show a saving in running or operational costs.
Priority Sub-classifications	(a)	Meet Statutory obligations
	(b)	Meet Health and Safety requirements
	(c)	Avoid serious disruption

An example of the approach adopted in the priority classification system in Table 2 would be an electrical distribution centre with a leaking roof causing damage to the switchgear. this would be priority 1 as it is essential to sustain the power supply to the site. It would have an (a) sub-code because of the legal requirement to keep high voltage systems safe and a contractual duty to maintain supply to occupiers. A (c) sub-code would also be appropriate as loss of power supply would disrupt the activities of occupiers; also some switch gear has to be built to order so it is imperative to stabilize the environment to reduce the risk of failure.

The two most urgent classes (Levels 1 & 2 in Table 2) usually need to be addressed within two years. However, certain work needs preparatory activities, for example in depth appraisals or design studies. Often these cannot be prepared in a short time. In such situations holding repairs may be required but for complex works the time factors and cost of preparing option studies and designs for major repair work need to be built into the work programme and the general maintenance policy.

When the most urgent work has been identified the period of time over which less urgent work may be placed can be determined. Start years can be allocated to work items shown in condition surveys or other appraisals as being justified to be new starts within the next five years. Start dates for projects which are forecast to occur more than 5 years hence may become nominal as they may have , in any event, to be rescheduled to accommodate more urgent work which may identified in the intervening period.

The nominal start dates for later start jobs have some value as it permits expenditure over time curves to be drawn. In an estate of varied age and type which has not been grossly neglected the profile may tend to taper off after a few years or may undulate. In such cases smoothing by shifting some starts may be desirable.

If the property portfolio has several similar buildings of roughly the same age expenditure curves may rise suddenly when the buildings are about 20 years old raising the scepter of a "maintenance time bomb" [Spedding, 1994]. The cause is often related to simultaneous expiry of external elements such as windows or felt flat roofs with engineering items such as heating plant and light fittings.

3 Use of other attributes for prioritizing maintenance

The use that the building or accommodation is put to, may influence the prioritization of work as much as its physical condition. Indeed six major criteria have been identified [Spedding, 1994]. These criteria are Building Status, Physical Condition, Importance of Usage, Effect on Users, Cost Implications and Effects on Service Provision. (These terms are described in Addendum A).

Such attributes enable rankings and weightings to be placed on individual schemes and provide the basis for decision making and finer tuning of programmes. A score range of 5 is usually adequate for most criteria to cover the range from essential to desirable but not critical. It is imperative that the order of ascendancy of the score is uniform to permit them to be added. If all other criteria are of rising importance; very poor physical condition must be 5 rather than using the high score to mean 'excellent no work required'.

These standard attributes may need to be expanded to accommodate special features of the building. Additional points can, however, be added to cover specific buildings or needs such as legal requirements, keeping historic buildings in good order, maintaining a facility of regional or national importance or to avoid criticisms or political consequences of repeating previous failures. If it is believed criteria are not of equal relative importance they can be separated by weighting factors. Generally condition or cost scores will tend to have a low rating than those related to usage or public service factors.

It should be noted that the attributes used to fine tune priorities relate more to how the building is used than to physical condition or cost. Maintenance managers require a good understanding of how the buildings are used and should involve the users in the decision making process. A procedure for discussing the prioritizing of the most urgent work with clients was introduced for the management of the UK government estate in 1985 in order to make sure that occupiers and building managers were aware of the impact of the proposed work [PSA, 1985.b].

4 Minimization of disruption

The actual condition of the building or some of its elements may cause a maintenance scheme to be identified and prioritized. However, the needs of the building user are a deciding factor of when and how the work is done [Kubo et al, 1994]. Timing in order to minimize difficulties to the occupier is a major consideration. Some building users have closed or quiet periods when work can be accommodated. For example, schools closing for holidays, food processing plants which handle season crops and may close down process line, or energy installations where plant can be shut down during periods of low demand. Most other building types do not offer this facility.

If inconvenience of maintenance activities cannot be avoided careful planning is needed to reduce its effects and mistakes in planning and execution. Disruption is a consideration which is part of the prioritization system used for UK government offices [Property Holdings, 1992] - See Addendum B.

The degree and cause of disruption varies with the type of work. Noise can be controlled by scheduling the noisiest activities to early morning, lunchtime and late afternoon. Moderate dust levels can be controlled by screens. If the noise levels are high and cannot be limited at justifiable cost or if dust may include toxic substances the safest approach is to relocate the occupiers.

Disruption may be reduced by grouping activities. The logic for grouping them may be that work items have similar service lives and need replacing at about the same time. The reasoning for carrying out the works together may be reinforced if they are in close proximity. Another reason may be the availability of access equipment or contractors plant, substantial saving in used charges and contractor's mobilization costs if such equipment is shared on one contract rather than being brought back a short time later if the jobs run separately. The effects of noise, increased fire risk, health hazards or obstruction to movement will often cause occupiers to be moved out. Savings can be made if the current occupier is expected to depart at end of the tenancy or if they are planning to move in anticipation of a refit of their accommodation for other reasons. Refits and refurbishments may be driven by needs of the occupiers where a building needs to be in sound condition for the installation of new equipment.

One case of building elements having similar life spans is windows and some services installations. The linkage is more noticeable in the case of heating systems, simultaneous replacement may be easier to arrange in summer when the heat producing plant is not in service and the effects of reduced weather enclosure can be more easily tolerated. In some cases the heat emitters may be on the perimeter of the building. If occupier has to be moved away from the windows to permit their replacement, access can be provided to the heat emitters at the same time. If the new windows are double glazed units in place of single ones it may be possible to down rate the output of the heating systems to achieve savings in capital cost and make energy economies.

Many roof repairs require access equipment on the facade usually in the form of scaffolding. The additional cost of modifying the scaffold to permit other work to proceed is marginal compared to that of erecting it a few years later to do other work on the exterior of the building. Repair or replacement of windows, external decoration or maintenance of cladding systems can be undertaken along with roofing work whilst the scaffold is in place.

Some installations require a good internal environment if they are not to deteriorate quickly. If an internal refit is planned the state of the external envelope of the building should be checked first. There is little purpose in replacing elements like ceilings and lighting

systems if the roof leaks. In some cases it may be necessary to bring forward re-roofing and similar work if it is expected that replacement will be necessary within the first third of the internal work's expected life span.

Improved techniques have been developed for estimating service life [ISO, 1998]. These can assist maintenance managers in predicting when work may be required and to identify simultaneously or closely occurring repair events. In some cases service lives can be adjusted by changes in specification or in use maintenance so that service lives coincide. If one element may cause another to fail it may be possible to ensure the one which could cause more general deterioration has a linger service life than the vulnerable element or at least is capable of being kept to a satisfactory level of performance by unintrusive maintenance procedures. If there is a long life critical non-building installation the building may need to be more durable than usual so that building operation which could disturb the installations are kept to a minimum. This would have applied to computer suites in the days of main frames but there are similar requirements for communications centres and medical facilities.

Service life planning and forecasting systems can be used as part of the design and facility management process. If elements are close together and influence each others performance it may be worth adjusting their service lives so that they are similar. This can be done by improved specification, weather protection or maintenance. In some cases it may be worth reducing the specification of the system with the longer life if it is more cost effective that extending the life of the other. This can be tested through value engineering or service life design and performance audits. This procedure could be used for non-structural external elements such as cladding panels or windows set against heating systems. Both systems are near the building perimeter and the thermal performance of the cladding determines the output of the heating system.

Major internal rearrangement is often seen as having a great impact on lighting systems and heating controls. This may lead maintenance managers to review the adequacy of these elements during such a refit. However such changes often have affects on movement in and around the building and impinge on fire protection and evacuation procedures. These systems must not be overlooked at such times. The changes in the electronic functioning of fire detection and alarm systems over a relatively short timescale is such that it may be difficult to modify these systems. Accelerated replacement to sections of the system or sometimes the whole of it, may be needed during even a modest refit operation.

One of the risks of combining maintenance schemes into one project is the overall cost. This may create difficulties in accommodating such a large item into an annual programme or if it is not of the highest priority it may be a target for delay to assist budget changes. If necessary these should be backed up by investment appraisals, schedules of short term savings and statements showing the impact on corporate operations. These will improve the programme's chances of survival intact when presented to management boards.

5 Conclusion

Although maintenance requirements may be identified through building inspections and condition audits, the prioritizing of the work may be decided through other criteria. The needs of the organization can be shown to be as important as the condition of the building. Accommodating the work at reasonable overall cost and with minimum physical impact on occupiers is of increasing importance.

A novel approach bringing in value engineering and attribute driven selection and weighting can assist the maintenance manager in making optimum decisions for the benefit of both the estate and the user organization. This can also be linked to value engineering and service life planning so that optimum performance, serviceability and return on investment can be delivered to the client.

6 References

Adonandoy, (1994) Customer orientated renovation and modernization process for multi-storey apartment buildings (p805-812). *Structures and Technology for Maintenance CIB W70.*

Bushell, R. (1981)Assessing maintenance priorities -guide-lines based on health service experience. *IoB Maintenance* Paper 17.

DWPT. (1990) MoD Manual 18. *Defence Works Service*

ISO. (1981) ISO 15686 (Draft) *Buildings - Service life planning,. Part 1: General principles, ISO.*

Kubo, T., Takakusagi, A. and Takara, T. (1994) On the Characteristics of tenants from the standpoint of Building Maintenance, *Maintenance and Modernization of Buildings*, CIB W70.

Property Holdings. (1992) Commissioning Code , *Property Holdings*, London.

PSA. (1985)a Accommodation and Works Circular 29/85 *Property & Services Agency*, Croydon.

PSA (1985)b Accommodation and Works Circular 45/85 , *Property & Service Agency*, Croydon.

Robertson, J. (1983) Maintenance Audit. TIS paper No 25 *Chartered Institute of Building.*

Smith, R. (1985) Condition appraisals and their use. TIS paper No 52 *Chartered Institute of Building*

Spedding, A., Holmes, R. and Shah, G. (1994) Prioritizing major items of maintenance work in large organizations. *Support systems for managing maintenance and modernization* p1263-1270. CIB W70 (1994)

Addendum A

Criteria for attribute based prioritization

Attribute	Code	Description
Building Status	**BS**	The relative importance of the building (where the defective element is examine) compared to others, in terms of function, current and intended future usage, e.g. an infant school might have higher status than a leisure building.
Physical Condition	**PC**	The physical condition of the defective element being examined, and its possibility of breakdown or failure, e.g. elements in very bad condition would be given higher priorities than those in fair condition.
Importance of Usage	**IU**	The importance of the functional unit (in relation to other units within the same building) where the defect is situated, e.g. the reception area would be more important than storage rooms.
Effect on Users	**EU**	The effect of breakdown or failure of the defective element(s) on the occupant and users of the building (including staff and members of the public), e.g. a problem relating to health and safety would be more important than an aesthetic problem.
Cost Implications	**CI**	The cost implication of breakdown or failure of the defective element(s) on maintaining the overall condition of the building fabric and building services, e.g. a defective roof would be given priority because if not repaired promptly, the eventual cost will be higher due to possible damage to other building elements
Effects on Service Provision	**ESP**	The cost implication of the breakdown of the defective element(s) on the provision of services for which the building is designed and used.

(After Spedding et al - "Prioritising Major Maintenance items of Maintenance in large Organisations ")

Addendum B

Maintenance Prioritization - Action and Effect Classifications

Class/Group	Priority Code/ Sub-class	Description
Maintenance Priority Classification	Priority 1	UNAVOIDABLE WORK: Schemes which cannot be deferred, without breaching statutory obligations , health and safety, seriously affecting occupier's operations and functions, security or to meet lease or covenant obligations to landlords.
	Priority 2	ESSENTIAL WORK: Schemes which cannot be deferred without serious penalties such as damage to property or increased cost.
	Priority 3	URGENT WORK: Schemes which are highly desirable to maintain the value and utility of the estate.
	Priority 4	DESIRABLE WORK: Schemes which are necessary to maintain property standards, or which would show a saving in running or operational costs of the property.
Maintenance sub-classes	A	Meet statutory obligations
	B	Meet Health and Safety requirements
	C	Avoid serious disruption and effect on client operations
	D	Prevent severe physical deterioration of property, or to meet requirements of lease.
	E	Avoid disruption of client operations
Effect if deferred	1	Failure to rectify defect or undertake ,maintenance work will result in RAPID, consequential or subsequent cost or nuisance to use of building
	2	Failure to rectify defect will have a SIGNIFICANT effect
	3	Effect of delay will be MARGINAL
	4	Effect of delay will be NEGLIGIBLE
Disruptive Effect on Occupant	X	Major inconvenience/disruption to occupants' activities.
	Y	Minor inconvenience/disruption to occupants' activities
	Z	Minimal inconvenience/disruption to occupants and will not affect to any degree occupants' activities

Example: Priority 2D1Z categorizes the requirement for Serious Non-Structural Fabric Defects being Essential//Prevent Physical deterioration/Rapid cost penalty/Minimal effect on occupant.

Based on the maintenance classification system in Property Holdings Commissioning Code (Property Holdings, London, 1992)

153 DEVELOPMENT OF AN INTEGRATED CONSERVATION AND MAINTENANCE MANAGEMENT REGIME FOR HISTORIC MODERN MOVEMENT BUILDINGS

B.M. Major

Mill House Magna Limited, Mayland, Essex, UK

Abstract

This paper adopts the premise that an increasing number of buildings, from Bauhaus onwards, will become designated as historic buildings for conservation as part of the world's historic and architectural heritage. This trend can be predicted and accommodated to provide suitable asset management. The advance of repair technologies for the structural components can be integrated with those of other major components as the starting point for a maintenance strategy which can be expressed in generalist terms although practically tailored to the individual building.

Keywords: Conservation, Modern Movement buildings, repair techniques, asset and maintenance planning, performance of repairs, life cycle costs, service life.

1 Introduction

This paper does not seek to introduce new research but to point a way forward for the application of technology and methodology expounded in previous papers and in new initiatives to provide a cost effective approach to the conservation and maintenance of an important part of our built heritage.

2 Background of listing modern movement buildings in the UK

The UK is extremely rich in its built heritage and administratively each area, England, Scotland and Wales has its own heritage body to list buildings of sufficient importance to be protected by legislation, namely English Heritage, Historic Scotland and Cadw.

Durability of Building Materials and Components 8 (Volume Three). *Edited by M.A. Lacasse and D.J. Vanier*. Published in 1999 by NRC Research Press, Ottawa ON K1A 0R6, Canada. ISBN 0-660-17742-0

The arrangements and criteria for listing are similar in each area but there are regional variations and for this reason the main text references will be to the English system for purposes of simplicity.

In England alone, according to figures supplied by English Heritage in April 1998, there are some 500 000 listed buildings and monuments, divided into 3 categories, Grade I, Grade II* and Grade II of which the two highest categories namely Grades I and II* represent about 6% of the total. The list is not static, currently less than 1000 inter-war and post war buildings are listed and this number will continue to grow in the new millenium as the relative importance of the genre and its seminal buildings becomes more apparent from the perspective of a new century.

In its guidelines for conservation of listed buildings the government ministry responsible does not differentiate between the treatment of 20th Century buildings and any others. Buildings less than 10 years old may not be listed.

3 Why modern movement buildings are different

Heritage buildings from past centuries are often rare and of traditional materials and craftsmanship. As mass production and media communication became universal from the start of this century a truly 'International' style of Architecture developed using new technologies or new developments of old technologies which transcended local vernacular forms.

It is true to say that those buildings which were at the forefront of technology and therefore the most likely to be listed were also those in which the pioneering nature of the design has lead to the first examples of maintenance problems and obsolescence requiring specialist solutions. Original specifications for such buildings having been revolutionary rather than evolutionary unlike those of previous eras.

In conserving modern movement buildings we have to respect the language of the Architecture and often it is still being spoken by the Architect or his/her immediate successors. In many cases the original architectural and engineering design solutions are still available and the provenance of the materials and components readily apparent. The approach which is taken may well depend on the speed at which a particular component or material has become obsolete since the original design and on the availability of matching material.

The materials and designs requiring our conservation expertise are those of the modern world, reinforced concrete, steel, aluminium, fibreglass, as opposed to traditional material such as bricks, mortar or clay tiles. However, the improved technology applied to many of these materials has altered just as it has done for vernacular materials and designs over the centuries.

In selecting modern buildings for listing there is a conscious effort to apply aesthetic appreciation in listing the best buildings of their era together with recognition of pioneering use of design form and materials rather than in much older buildings where the need is to conserve remaining rare examples and buildings having long historic associations with famous people and events.

It may well be that some of these buildings may have stood the test of time without listing but it is more likely that commercial pressures would have compelled drastic change or wholesale replacement within a relatively short time scale, especially where land and rental values are high.

4 The underlying trends in repair and maintenance costs

The capital costs of repair and conversion to a listed modern movement building are likely to be higher than those for an equivalent unlisted building of similar materials and components. This will be mainly due to the need for additional research and consultancy service to ensure that the building is authentically repaired and also, if alteration is required, that it is in keeping with the spirit and intention of the designer and the tailoring of repair technologies to suit the individual building. It also has to be borne in mind that the delays inherent in seeking Listed Building Consent for work which requires such permission may also have a bearing on costs. The extent of any cost uplift will ultimately depend on the condition of the building and its previous maintenance history.

We can use information gathered by the BRE (Building Research Establishment), published in the summer of 1998 and widely reported by Building Magazine and other trade papers to demonstrate that over the last 10 years in the UK maintenance costs have rocketed by a staggering 87% over the building sector and that the running costs of a building cost 6 times as much as the original investment. Given that whole life performance is about optimizing expenditure, not just long life buildings, it is as important to avoid unnecessarily expensive options for listed buildings.

5 Life cycle costing

This paper does not intend to go deeply into the theory of life cycle costings but to emphasize the need for a proper balance between capital costs and future operating costs.

There is some resistance among building owners to the full implementation of life cycle costing for the following reasons:-

- The feeling expressed that life cycle costing deals with the future and that since this is uncertain the results of the costing will be inaccurate.
- The problems of generating data on which life cycle costing data is based.
- The feeling that the quasi-scientific basis of life cycle costing deprives a manager of decision making flexibility.

In response to these concerns we can only say that all change is uncertain but we can still use information to improve decisions and incorporate elements of risk and uncertainty into cost projections. Avoiding big surprises is better than opting out and proper cost planning is more important than the lowest priced option for initial capital expenditure on repairs. Risk analysis techniques can be used to minimize the surprises and design/specification changed to reduce uncertainties. Data bases are now more comprehensive and better researched, allowing the life cycle costings to be tailored to particular decisions.

Life cycle costing remains a guide to decision making not an absolute and is dependent on input from the manager.

We are looking at the balance between initial and future expenditures which is as applicable to a historic building as any other. Spending money judiciously now may appreciably reduce future expenditure and with the emphasis on aesthetic quality of conservation work reduce disruption during restoration and planned (or do I mean unplanned) maintenance.

Some of the benefits of life cycle costings for historic buildings are not immediately obvious in that outside bodies have some control of the materials and aesthetics employed, nevertheless there is a beneficial result to be derived for the design process.

Firstly the designer must understand the technical issues relating to the components and materials, actual anticipated life expectancy, performance characteristics and application of life cycle costing techniques. These are wide issues and can only be addressed in crude terms in this paper.

6 The importance of testing and diagnosis

No building can be properly assessed for application of any repair or maintenance initiatives without application of good survey techniques. This is particularly true of reinforced concrete and steel frame structures, which are the prevalent forms for modern movement buildings. The exact measure of how much concealed corrosion or potential corrosion is hiding behind the visible façade is one of the main determining factors in the application of appropriate repair strategies.

The full range of hammer testing, cover meter, half cell, carbonation and chloride testing, as well as even more precise techniques, allow a full evaluation necessary for cost comparisons.

We also need to know some important financial variables:-

- A discount rate must be selected to take into account the time value of money.
- The period of analysis for appraisal – In the UK cost planning is usually over a 30 year period but for US federal buildings for example the period is normally 25 years.
- Allowance must be made to handle future inflation for expenditure.
- The impact of taxation must be considered. The anomalies of the UK VAT system are such that new construction is zero rated but repairs attract 17.5% VAT. Listed historic buildings do have zero rating for those works which require Listed Building Consent but the tax position is generally unfavourable to refurbishment and repair work. Tax parameters can be changed at any time.

7 Traditional repair techniques versus New technology

When dealing with concrete repairs the accepted solution has been to hack off all areas of concrete which are spalling together with all concrete in the carbonation zone, treat the rebars locally and then carry out cementitious repair before application of coatings etc. This is enormously destructive of the fabric and for a historic building the loss of such a degree of original fabric and surface modulation can be disastrous.

Similarly for a steel frame building clad with a fragile and obsolete panel form, large scale intervention to deal with corrosion in the frame can have a permanent and tragic effect on the appearance of the façade.

The new technologies we are using to minimize such excessive disturbance are those such as cathodic protection, re-alkalization and migratory corrosion inhibitors.

A DETR (Department of Environment Transport and Regions) research project recently completed indicates that as much as 50% of initial costs of treatment to facades of historic steel framed buildings can be saved as a result of applying cathodic protection. Furthermore the implanted anodes are said to have a life of 50 years plus. The major costs being in the replacement of cabling and other electrical equipment after say 25 years. The implications of such savings for the cost planning exercise are obviously of radical importance.

Historic buildings have already stood the test of time, they were built to last. Just because a building was at the cutting edge of technology and mistakes were made or the use for which it was built is obsolete does not mean it has no residual value. The important thing is not to separate capital and revenue expenditure but to integrate budgetary control so that the choice of repair system or the impact of repair rather than replacement can be fully evaluated.

It is easier to get large conglomerates or prestigious public bodies, for whom the possession of a landmark building is a matter of corporate pride, to face up to forecasts of future expenditure. Also prime position listed buildings in town centres are likely to perform well as they have high rental values. Crisis maintenance is a fact of life but for capital restricted building owners it is the norm.

It is frequently said that developers have no interest in life cycle costing because running costs will devolve to somebody else. Increasingly purchasers/lessees of listed buildings are becoming more aware of running costs and service charges and will want to see that the correct balance between current expenditure and future revenue has been struck before purchase. Landmark buildings are now in the domain of international investment and investors will demand to know their commitments for short and long term expenditure.

8 Case studies

8.1 St. Ann's court

This is an elegant three storey 'International Style' house executed in reinforced concrete based on a segmental circular plan form. It was constructed in 1938 and it is one of the earliest known examples of shuttered board marked concrete in the UK. The Architect was Raymond McGrath and the property is listed Grade II*.

The repair and refurbishment of the concrete represented a large proportion of the external refurbishment costs required to be carried out for a new owner. The various options for repair were considered. The need to conserve the original board marked marked concrete coupled wit a necessity to delay indefinitely the onset of corrosion in the rebars which were in carbonated concrete were the main criteria which governed the choice both aesthetically and technically. Fortunately the select repair system using migratory corrosion inhibitor was also the most cost effective option.

The area of original concrete and previous repair which required cutting out represented only a very small proportion of the wall area which had been previously identified by testing, although the majority of rebars were in the zone of carbonation. A traditional concrete repair method would have required all the carbonated concrete to be removed. Cathodic protection and realkalisation were inappropriate due to lack of electrical continuity, difficulty in concealing anodes and cost.

The migratory corrosion inhibitor was applied after cleaning off the old coatings, cementitious repair and pore filling and finishes applied subsequently. Tests were carried out to ensure that the corrosion inhibitor had migrated to the rebars and formed a passivating environment. Fortunately the building had always been coated so the overall condition was better than might have been anticipated in a 60 year old building. All the repair materials and coatings are guaranteed for 10 years. At the end of the 10 years the coatings will be ready for replacement and fresh testing is scheduled by the manufacturer of the repair system to ensure that the corrosion inhibitor is still working at that time. Provided that such preventative procedures are built into the maintenance plan the future expenditure can be anticipated and controlled.

The 10 year testing will involve the erection of a tower to permit testing to be carried out in selected locations, removal of samples, laboratory analysis and minor making good following re-cleaning and renewal of pore filler and renewal of coatings. A predictable and calculable operation for inclusion in the cost plan.

The capital cost of repair works to the external envelope of the property including concrete repairs equated to approximately 1/10 the capital cost of the property purchase figure and 1/20 the enhanced value of the property on completion of the works.

8.2 Keeling house

Local government owned cluster block listed Grade II* in reinforced concrete, designed by Denys Lasdun. In situ concrete with portland cladding panels. Built in 1959, very early for the UK as 'streets in the sky' public housing in a tall building. The rebars have low concrete cover and mass placement techniques were used giving characteristics of carbonisation of concrete close to steel, steel corrosion and large areas of spalling to the unclad in situ concrete. The building also suffers from poor insulation, single glazing and insecure and unattractive common areas. It is located in a traditionally poor area of London's East End with equivalently low property values although it is geographically near the City of London.

At the time the feasibility study was carried out the cost of the necessary work was in excess of the capital value of the property. Capital values were known to be due to 'gentrification' but were insufficient to cover the cost of works required to meet conservation criteria. It was considered that only by gaining grant subsidy through the Heritage Lottery Fund could the shortfall be met. English Heritage were extremely helpful in their approach to the study and readily co-operated to make sure the proposals met with the requirements to obtain funding.

Accurate assessment of future expenditure was vital to demonstrate to financial lending institutions that an adequate sinking fund could be allowed to ensure the integrity of the structure for the life of the loan.

As the building was threatened with demolition at the time the feasibility study was carried out, the results of the study were germaine in allowing English Heritage to prove to the building owner that a viable scheme of repair was possible and therefore consent to demolition of a listed building could reasonably be refused.

The concrete repair represented a very important factor in the overall repair package. A full structural survey was carried out by abseiling the building. Tests being carried out as previously described. A fixed price was then obtained from a specialist contractor for a repair methodology using migratory corrosion inhibitor. The manufacturer of the system agreed in this case to provide a 15 year guarantee on the materials which allowed for costs of re-testing, cleaning and recoating to be allowed at the halfway point of the 30 year cost plan. The future data would be gathered by abseiling specialist teams which would keep access costs to a minimum. The cost plan prepared from the data proved that the future of the building could be ensured by adequate and affordable maintenance funding.

8.3 The Joshua Hoyle building

Although this building is pre 'Modern Movement' it is an early example of a steel frame building with Grade II listing which required conservation of a largely terracotta cladded façade whilst addressing the problem of corrosion in the steel frame. As such, it is a model for dealing with younger buildings in which the steel frame corrosion is only now becoming apparent. This particular building formed part of a study for the DETR carried out by Taywood Engineering.

In this case cathodic protection was the selected method given the electrical continuity achievable in the frame. The advantage of the method was minimal disturbance of the façade in comparison to that of full removal of cladding required by traditional methods.

As complete removal of the façade was not required, obvious and substantial cost savings have accrued, while providing a solution ideal for the conservation of the fabric. It is claimed that up to 50% savings provided compared to traditional repairs using this method and ongoing monitoring equipment has been built in to allow continuous, remote assessment of the electrical readings over time.

The anode strips were easily concealed behind existing mortar joint positions and have had no structural or visual impact on the building.

8.4 The Willis Coroon building

Formerly the Willis Faber Building designed by Norman Foster. It was designed as the Headquarter building for a multi-national company and occupies a prominent corner site in the thriving provincial city of Ipswich. This building was erected in 1975 and is not therefore yet at the stage of requiring wholesale remedial work. It is listed as Grade I and was the first such building to be the subject of management guidelines.

When the building was first listed the owners were less than pleased with a decision which they felt compromised their day-to-day business operations. To defuse the potential hostility of the situation a tri-partate agreement was drawn up between the owners, the local authority and English Heritage. The guidelines set out those matters which it is agreed do require listed building consent when work is carried out during the life of the building. The Architect's design intentions for the building were explored and given full weight for the purposes of defining these processes. Although not legally binding, the agreement gives clear parameters of what is understood to require ongoing consultation in the maintenance plan, definition of all matters covered by the agreement and gives a timetable for future review.

The exercise carried out has given the building owners opportunity to plan for future alterations and maintenance with many areas of uncertainty removed. This approach has been so successful that all historic building projects funded by the Heritage Lottery Fund are to be required to have an agreed set of guidelines based on this model.

It is clear that given a framework of these guidelines and the increased use of new technologies to prevent future structural deterioration a more accurate cost planning exercise can be applied to modern movement historic buildings.

9 Conclusions

There is an increasing need to look at the conservation of modern movement buildings in an innovative and cost effective way.

A great deal of academic research into new techniques control of material durability and repair needs to be assimilated into the mainstream of practical building conservation methods.

Increasingly buildings using the techniques will become more common if the methodology is clearly understood and the financial and managerial benefits appreciated.

It is important that practical research projects, such as those funded by the DETR receive the exposure required to marry technologies to real buildings, with properly monitored results.

Although this paper refers to the application of technology mainly for reinforced concrete and steel frames, the same principles would be applicable to new advances in repair of other building elements.

It is entirely possible to agree written guidelines which satisfy the conservation and user needs of the building.

Given the ability to monitor the effectiveness of new technologies in use and to build the cost plan around known life cycles of materials we can look forward to the development of ever more effective maintenance and management regimes for our modern movement buildings.

10 References

English Heritage (1996) Modern Matters. Principles in Conserving Recent Architecture. Donhead.

DETR Project Reference MT2C (1998). The Prevention and Repair of Corrosion in Masonry Clad Steel Frame Buildings.

Miller, J.B. (1994) Structural Aspects of high powered electrochemical treatment of reinforced concrete. *Corrosion and Corrosion Protection of Steel in Concrete*. Sheffield Academic Press.

Cherry M. (1995) Protecting Industrial Buildings: The Role of Listing. Leicester Archeological Monographs.

English Heritage (1995) Agreements for the Management of Listed Buildings.

Glass G.K. and Chadwick J.R. (1991) Factors affecting the corrosion rate of steel in carbonated mortars. *Corrosion Science 36*.

Thorne R. (1993) The right conservation policy for listed post-war buildings. *The Architects Journal 198*.

Mills E. D. (editor) (1994) Building Maintenance and Preservation: A Guide to Design and Management. Butterworth/Heinemann.

154 OVERALL SURVEY BUILDINGS — PERFORMANCE AND MAINTENANCE

B. Marteinsson and B. Jónsson

The Icelandic Building Research Institute, Reykjavik, Iceland

Abstract

The evaluation of the condition of a large group of buildings is very interesting from mainly two points of view. It gives very valuable and necessary information for planning future maintenance work and also some information can be gained about the performance of building materials, components and whole buildings under in-use conditions. In the former case, a good idea can be obtained on what kind of work is needed, at what expense, and even how urgently. In the latter case, it is clear that the results of inspection reflect the situation at the inspection time, and the problem remains on how former repairs influence status results. This paper presents a survey of 220 buildings in Reykjavik, Iceland, where the buildings were given visual external inspection with each surface (classified by orientation and the kind of material) being given a systematic rating according to three main criteria: the characteristic breakdown of materials; the percentage of breakdown and the need for repair. Information from the inhabitants/users of the buildings was collected on former maintenance work, and these people were also asked to give their opinion on the condition of the building. Information from the survey and from inhabitants was compared, and the result of the final evaluation takes both into account. This methodology will be discussed in the paper and some examples given showing what can and cannot be learned from such a survey

.

Keywords: buildings, field inspection, evaluation, in-use condition, maintenance

1 Introduction

In Iceland the number of new buildings has decreased considerably in the last decade and the average age of buildings is thus rapidly increasing. Likewise, building maintenance is a fast-growing specialty and hence it is worthwhile to gather information on its scope in the near future, and in particular, what its major tasks will be. In order to make such predictions, condition surveys of existing

Durability of Building Materials and Components 8 (Volume Three). *Edited by M.A. Lacasse and D.J. Vanier*. Published in 1999 by NRC Research Press, Ottawa ON K1A 0R6, Canada. ISBN 0-660-17742-0

buildings must be made, otherwise certain pertinent questions on future maintenance might not be answered. In addition to maintenance needs, it is useful to examine what information is available on material durability as well as the nature of deterioration.

Data gathering by inspection of buildings in use, rather than from models under experimental conditions, is an important means of learning about durability and the need for maintenance as has been discussed by several authors (Brandt 1984; Masters and Brandt 1987; Brandt and Sjöström 1993). Obviously, building condition reflects original quality, age, environmental influences and any maintenance previously performed. Inspection reveals only current status with the effect of former maintenance. The results of the most resent efforts is clearly detectable but in older houses the effect of former maintenance works is overlapping and the result of a single effort is diffuse. Therefore, in order to evaluate maintenance needs and predict future building condition, the importance of gathering information from residents/users about previous maintenance is also obvious.

In this conjunction, it should be mentioned that in Iceland there is a long tradition of building owners personally participating in the construction of homes, as well as playing a major role in subsequent maintenance. This actually can have a major impact, both fortunate or unfortunate, on the original quality of the building, and not least, the quality of future maintenance.

2 Conducting the surveys

2.1 Building sample

Examination of building condition was confined to Reykjavík (with a population of over 100,000 of the nation's 270,000 residents) in order to limit the scope of the survey. Reykjavík consists of about 26,000 buildings of various types, including a large part of the nation's service and commercial construction. The age distribution of these buildings is quite skewed, see fig. 1, with the main period of construction being the last 30 years, due to rapid increase of the area's residents and growing need for services.

In order to obtain information about these buildings, a random sample was chosen to reflect the whole group. In determining sample size, it is important to limit it in order to keep survey costs manageable, but not so much that information from it cannot be assumed to be typical of the whole from which the sample is drawn. At first glance, it seems that the necessary number of buildings in this case rather large, or 1,000-2,000 units, or similar to the number of persons considered if surveying residents. On closer examination, it is possible to justify a considerably smaller sample.would have to be

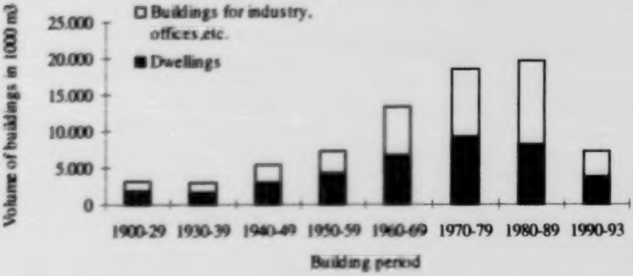


Fig. 1: Volume of buildings in Reykjavik related to building period

A building's status clearly reflects original quality, current age, environmental influences and maintenance during use;

- Buildings in the same area will have very similar environmental influences, though with some exceptions.
  1. Local pollution, for example from industry or considerable road traffic, can be quite variable. In Iceland, pollution is generally very slight, and its influence negligible, except for a concentrated area of Reykjavík's city centre and areas near the rare larger factories outside Reykjavík.
  2. The shelter effect differs from one building to another, but the average effect is probably similar throughout an entire neighbourhood. Condition can differ from one neighbourhood to another, and therefore condition varies according to building period (neighbourhoods are constructed at different times). Increasing sample size does not reduce this influence.
- Buildings of a similar construction period, and of similar type (single family, multi-family, industrial, commercial, service centre) are inherently similar, both regarding construction and internal deterioration.

Therefore, necessary sample size can be limited by dividing the whole into categories--first by age, i.e., using 10-year increments, then by types within each interval. Due to the relatively minor statistical weight of the oldest buildings, all structures built prior to 1930 were considered of one age category. Random buildings were then chosen from each age category until the complete sample consisted as closely as possible to 1% of buildings from each category, with a minimum of 10 structures from each sub-group. The final sample size obtained from this method was a total of 220 buildings, which the authors feel is adequately numerous to give a good indication of the whole.

2.2 Survey questions for owner/residents

For the chosen sample only the owner or resident can give some information on previous maintenance and recent expenses from unforeseen damage, such as leaks, which may have come up. Information from building owners will never be complete, often due to relatively short occupation of the current owner, or perhaps because of a natural human reluctance to remember negative aspects of residency. Upon surveying duration of residency, a rather sizeable group showed long-term residency, considering age of the structure in question, Table 1. The often long residency coupled with the tradition of self owned housing gives us a certain confidence in the value of the answers.

2.3 Condition survey

It was decided to use visual evaluation only, as material sampling would've proven too time-consuming.

Status evaluation can be considered in two ways: first, frequency of certain symptoms rating and second, scope of the given condition. This methodology has been previously discussed and explained in (Brandt 1984, Norwegian Standard NS 3424). Usually the evaluation of degradation, as such, is seen as the important aspect, but the importance of both considerations (frequency and scope) has not been stressed sufficiently. Recording frequency at which certain symptoms are seen, for example on given parts of buildings, will yield an idea of the kind of degradation, how often and even how fast it occurs. The condition scope is then less distinct and it is impossible to predict maintenance needs from frequency of degradation alone. Information on scope is obtained from overall condition of walls, floors and roofs and from volume calculations for parts of buildings based on architectural drawings. This makes it possible to determine the amount of affected surface for each symptom, and finally one can evaluate the maintenance needs. Conclusions from evaluations based only on frequency of damage, therefore, yields different information on overall condition, compared to scope surveys, and hence it was decided to apply a double evaluation to evaluate both frequency and scope.

Table 1: Length of occupancy in houses in Reykjavík (year 1994)

Length of occupancy, in years.	All houses (in %)	Occupancy related to the building year of dwellings (in %)							
		-1929	1930 -39	1940 -49	1950 -59	1960 -69	1970 -79	1980 -89	1990 -94
One or less	10	43	14	10		4	5	16	
Two to five	15	14		35	8	12	10	6	60
Six to ten	23		29	15	8	16	20	48	
Eleven to twenty	20	29	29	10	9	16	35	23	
Twenty one to thirty	11				17	32	20		
Thirty one to forty	6				33	12			
More than forty	6	14	14	20	17				
No time given	9		14	10	8	8	10	6	40

In addition to condition, maintenance needs were evaluated. This independent evaluation of the need for maintenance simplifies later estimates of maintenance costs, since rating the need for maintenance based only on condition reports is otherwise very time-consuming. In processing results it became apparent that the double evaluation gave a good indication whether there was harmony between evaluations on buildings, and if there was need to repeat a building's evaluation due to poor record-keeping or actual fault in the initial rating.

An evaluation key was used when examining buildings as was a detailed reporting sheet where examiners marked appropriate observations and recorded remarks. An introductory section covered general aspects of each building, such as type of structure, number of floors, external conditions (shelter, exposures) and building shape.

Each part of the building is described according to substance used (main materials first, i.e., concrete, steel and later, a more specific description); surface texture (smooth, corrugated, etc.); surface treatment (e.g. painting); fastening of panels; roof finish; and finally a special description about windows, detailing material used for the openings, the type of glazing, framing lists, and finishing at walls (caulking) and installation of windows which open.

The main purpose of the survey then deals with conditions of surfaces and estimates need for maintenance, both regarding surface finish (e.g. painting) and main material of the building (e.g. concrete in concrete walls and panelling in panelled surfaces. The main material of external surfaces was called underlying material in the survey to distinguish it from surface finishing. In order to obtain a standardised appraisal of degradation, a survey system was used which divides degradation into four stages, using the letters A through D. Each material then has its own description for these stages. For clarification, descriptions for concrete are shown below in Table 2.

Table 2: Concrete surfaces, description of surface degradation

Description	Surface finish	Underlying material
A- Undamaged	Clean, intact, unworn non-flaking	undamaged, no or very little damage
B- Slight damage	dirty, discoloured but intact so as not exposing underlying layers	Slight flaking, fine cracks with limited scope
C- Considerable damage	Flaking which exposes underlying layers	Some flaking, limited frost and alkali damage, some cracks
D-Severe	Widespread flaking	Much frost &/or alkali damage.
Lots		
condition	with underlying layers widely exposed	of cracks and other damage.

Thus, the attempt is made to divide each material into four, well-defined stages. But despite this, it is impossible to completely eliminate the subjective opinion of the surveyor. In order to minimise this impact, surveyors worked in pairs, with partners changing regularly to keep them fresh and improve the likelihood that evaluations between individual buildings would be comparable.

In addition to evaluating degradation, a number of questions were asked regarding type and quantity of damage or defect in material layers or makeup. In the case of concrete surfaces, assessment was made on type of crack network, chemical precipitation, rust damage, flaking, etc. Regarding wooden window frames, rating was done on wood weathering, raw framing, looseness of framing lists, etc. This specification of damage beyond general condition description is important for evaluating the exact deterioration process and for making cost estimates possible.

Scope of degradation or frequency of damage was then scored on a scale from 0 - 3, as shown in Table 3.

Table 3: Scope of degradation

	% of plane involved
0 = Minimal scope / rare defects	up to 5
1 = Some scope / occasional defects	5-33
2 = Considerable scope / widespread defects	34-66
3 = Severe scope / defects near complete	67 - 100

Whole planes were rated, one at a time, in the survey, regarding condition and scope of deterioration in accordance with the above, but such that each plane could be given as many as four scores with appropriate scope scores. However, total scores for each plane could not exceed the rating of three (3). For further clarification Table 4 gives an example of a concrete, south-facing wall.

Table 4: Rating of a concrete surface (underlaying material), vertical plane; south facing

Condition rated (per key)	N	S	E	W
A Undamaged				
B Slightly damaged	[ ]	[2]	[ ]	[ ]
C Considerable damage	[ ]	[1]	[ ]	[ ]
D Severe deterioration	[ ]	[0]	[ ]	[ ]

Interpretation: the wall is generally somewhat damaged;

34-66%	of the plane has slight flaking &/or fine crack networks of limited scope
5-33%	of the plane has some flaking on the surface, limited frost &/or alkali damage with cracks here and there.
-5%	of the plane has severe frost &/or alkali damage, widespread cracking or other damage.

This treatment gives a variety of possibilities for data processing;

- Incidence of worst damage:
  The worst condition scores, regardless of scope, give information about when certain damage first appeared, and therefore what maintenance steps are necessary.
- Condition frequency, pertaining to scope:
  Different condition descriptions resulting from a double rating-condition on the one hand, and scope on the other are in fact comparable when it comes to evaluating maintenance needs. Thus the maintenance needs of planes with the following scores are similar: B3A0~B3~A3C0 A2D1~A1B1D1 although it is obvious from the rating that the type of damage is somewhat different. The different groups found in this way can be ranged on a scale from 0 to 100 (100 scoring highest without damages or degradation) and an

average value or distribution can be calculated. It is therefore possible to group surfaces according to such condition scores as follows (the technique may vary with material rated):

1. Nearly undamaged
2. Mostly undamaged, slight degradation visible
3. Significant or much subtle degradation
4. Significant or much obvious degradation
5. Significant or much obvious, widespread degradation

Frequency of such categories gives considerable information on overall condition and need for maintenance.

Finally, surveyors rated the maintenance need for certain planes: repair of the surface finish on one hand, and need for maintenance of the underlying substance. Scores rated as in Table 5.

Table 5: Category description and need for maintenance

Category description	Remarks
A Condition good	no need for attention for the next 5 years.
B Adequate	Needs attention in 3-5 yrs.
C Poor	Needs attention in 1-2 yrs.
D Very poor	Repair as soon as possible, used if it is felt that damage may result from this part (e.g. leaks) or if a structural risk is at hand.

3. Survey conclusions

3.1 Owners responses

Home-owners in Iceland provide about 60% of maintenance labour themselves. However, this is changing, and own maintenance work in multi-family units is mostly interior painting.

Maintenance cost division shows that about half of costs are for interior maintenance and half for exterior maintenance.

Costs for maintenance are quite variable, according to the age of the structure. Figure 2 shows maintenance expense as a proportion of new building costs for residences. From home-owner responses it is possible to obtain quite a good idea of maintenance need in monetary terms, but the information about steps taken are often little. This is due to the fact that only in extensive maintenance works it is considered as feasible to make a special inspection of the building and then a job specification for the maintenance effort. The average annual maintenance cost for housings, calculated over 60 years, is 2 % of the building cost for a new house, which is very similar to figures published by others.

The information from the owners indicate that concrete walls have required extensive maintenance and a portion of them has been cladded due to deterioration of the concrete surface, see Table 6. The heavy maintenance required by the walls built in the period 1960-1980 is due to great problems with alkali-reactions, but corrective measures made on the cement production in 1979-85 have resulted in that this is not a problem in concrete produced since then.

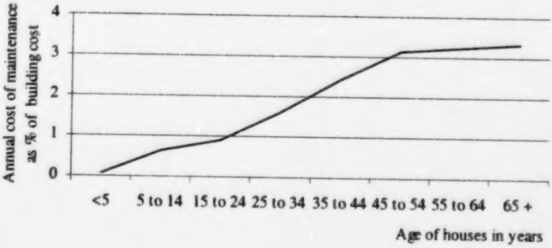


Fig.2: Annual cost of maintenance as a fraction of building cost

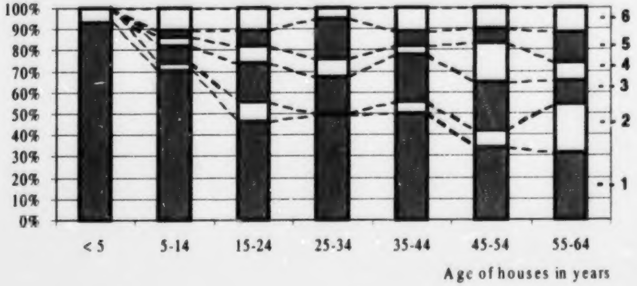
Table 6: Former maintenance of concrete walls; shown as ratio of all houses

	All houses	Building period -1930	 1930 - 39	 1940 - 49	 1950 - 59	 1960 -69	 1970 -79	 1980 -89	 1990 -93
Repair of concrete	33	20	33	40	44	47	31	29	
Wall cladded		12			30		18	25	4

3.2 Status survey

A sequential order of different damage events and the relative significance of each incident can be obtained from the double status rating (frequency of symptom plus scope of symptom). A frequency survey generally shows a gloomier picture of status, compared to a scope survey, as the former considers damage or deterioration as soon as they are visible, regardless of scope or severity. Condition survey indicates how a given material deteriorates and also the expected service life of building parts. On the other hand, it is difficult to determine the frequency of maintenance needs from such surveys.

Results from condition surveys of concrete external walls are shown in Fig. 3, with distribution according to age group, average condition and also average scope of prior maintenance. Even though extensive maintenance has been performed on houses from all building periods until 1990 (see Table 6), typically 11 - 28% of the walls are in poor condition and about 10% of the walls additionally have been cladded due to concrete damage. Cladding on houses aged 5-15 years is either planned from the start or decided upon due to adverse discussion on durability of concrete. The condition of all the walls in houses 15 years old, or older, is classified as acceptable or good in only 40-50% of the cases.



1. The condition is good
2. Slight degradation with limited scope
3. Slight degradation, the scope is medium degradation
4. Significant or much subtle
5. Significant or much severe degradation
6. Cladded walls

Fig. 3: Condition survey of concrete walls

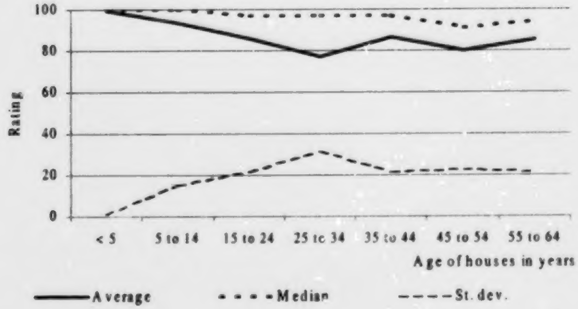


Fig. 4: Condition of walls in values of average, median and standard deviation

By rating status using scores 1 (poorest) to 100 (best) it is possible to calculate distribution within each age group. The resulting distribution curve in each group definitely does not show normal distribution as can be seen on the difference between average- and median values, fig 4. The distribution for some building ages is very skewed with a longer tail towards poorer condition. Therefore, it is necessary to use particular care in evaluating results, as averaging can give a misleading appraisal of condition.

In Iceland's wet climate, surface finishing in many cases has a major influence on the condition of underlying material. The survey clearly showed that quality of surface finishing was often very low and therefore gave inadequate protection to underlying material. In the case of windows with wooden frames of low original quality, their condition steadily deteriorates until window replacement becomes necessary. With windows frames of high initial quality, the problem is mainly that frequency of surface maintenance increases abnormally due to poor finish durability, until it becomes necessary to strip paint from the wood and refinish, and also repair any damage which may have occurred, then treat the surface as if it were a new frame.

A large portion of wall surfaces, taken from any given age period and which now rates in good condition, has never needed maintenance to speak of. The condition of the material seems to be more dependant on initial quality than on maintenance. Concrete which is poor quality from the start will be a heavy maintenance burden, and ultimate quality will never be adequately good. In these cases it may prove necessary to renew the outermost underlying layer of the wall using replacement material which will tolerate environmental factors. But this concept seems difficult for building owners to understand. The owner, and often his consultant too, overrates results of normal minor maintenance on concrete and has a tendency to make cosmetic repairs only to visible damage. The structure continues to deteriorate and rarely are all aspects of the building entirely in good shape at any given time, or even one type of building components such as the concrete walls. Therefore, building repair processes are repeated at regular intervals, e.g. typically concrete repair is needed every 5-7 years. Each repair seems to come as a surprise to owners, who do not understand why the previous repairs did not prove adequate. Hence, there is a serious need for much better ways to conduct surveys and make predictions relating to building maintenance.

Results show that degradation has typical patterns for each material, but due to previously performed maintenance, it is difficult to predict the rate of deterioration. On the other hand, it is possible to estimate the average "service life" of different materials with some certainty, but existing distribution is quite variable between buildings, see Table 7.

Table 7: Service life of building materials in Reykjavík, Iceland - common and extreme values

	Service life (years)	
	Common	Extreme
• Galvanized steel claddings		
1. Roofs -		
The cladding material	35 - 45	15 - 100+
Coatings; Industrial	10 - 15	5 - 20
Coatings ; Painted in situ	10	8 - 15
2. Walls		
The cladding material	>60	25 - 100+
• Windows of wood		
Wood -mainly Nordic Pine	35 - 40	4 - 80+
Coatings	2-4	1 - 10
• Concrete walls (see fig 7)	>60	15 - 100+

Results of the condition survey as discussed here show the present need for maintenance and what that entails. In the process, it proved feasible to make predictions on the need for maintenance and estimate costs for the next 20 years. According to our sample, this cost is now equivalent to 30% of the entire construction budget. In the next 20 years the cost of maintenance will be double as high because of higher age of now existing buildings and new buildings added over those 20 years, while the market for new building construction is expected to remain the same.

4 Acknowledgement

This paper is based on a research project done by the Icelandic Building Research Institute (Jónsson and Marteinsson 1997) with financial support from the Icelandic Research Council and the State Housing Board.

5 References

Jónsson, B and Marteinsson, B. (1997) Construction status and maintenance requirements. *IBRI Report 97-14*, Reykjavík.

Brandt, E., 1984, Assessment of the condition of buildings, in *The third international conference on the durability of building materials and components*, VTT, Helsinki, Vol 2. pp.433-9

Masters, L.W. and Brandt,E., 1987, Prediction of service life of building materials and components, in *CIB W80/RILEM 71-PSL-Final Report*, RILEM Technical Committees

Brandt,E and Sjöström, C., 1993, Field Exposure Tests, Experimental Buildings and In-Use Testing, in *Durability of Building Materials and Components 6*. Edited by S. Nagataki, T.Nireki and F. Tomosawa, pp. 1051-60

Nowegian Standard NS 3424, *Condition survey of construction works*

155 CONDITION SURVEY AS FORMAL AND PRACTICAL TOOL IN FACILITIES MANAGEMENT

S. Nes and P.J. Hovde

Norwegian University of Science and Technology, Trondheim, Norway

Abstract

This paper presents a strategy for budgeting and planning for maintenance in addition to presentation of a method for revealing status and need for maintenance for construction works. A method enabling stochastic handling for cost estimating in maintenance planning is presented in addition to a budgeting philosophy utilising the principle of annuity.

Keywords: Maintenance planning, annuity, stochastic, handling maintenance budgeting, condition survey.

1 Introduction

As a building enters the phase of service life, maintenance costs tend to be systematically underestimated and therefore resulting in accumulating deterioration and accelerated decreasing value. Most buildings have an accumulated state of damages – most often not visible, or with symptoms hard to interpret. The design, composition of materials, level of maintenance in addition to knowledge of the importance of deterioration mechanisms decides the development of damages. The level of maintenance can presumably be traced to strategy for budgeting. Poor maintenance yields damages over time. An acceptance for using the annuity principle for expenses to come for areas not momentarily affected by the use of money will establish a predictable and reliable situation for budgeting.

It is important to utilise tools and methods for objective and unambiguous diagnosing of buildings and construction work. The purpose of this paper is to briefly present a method used in Norway for condition survey, and to relate this method to maintenance planning and control. The method is described in the Norwegian Standard NS 3424.

Durability of Building Materials and Components 8 (Volume Three). *Edited by M.A. Lacasse and D.J. Vanier*. Published in 1999 by NRC Research Press, Ottawa ON K1A 0R6, Canada. ISBN 0-660-17742-0

One has to accept the uncertainty of cost estimating planned actions, even if similar actions are well known. A method enabling stochastic handling of worst/best estimates is presented for cost estimating in maintenance planning.

2 NS 3424 – a brief description

The purpose of the standard "Condition survey for construction works", (NBR 1995) is to achieve a largest possible degree of objectivity in evaluation of the built environment.

The standard is used in facilities management for identifying the status regarding damages and degradation of the built environment for mainly five purposes:

1. Damage control
2. Maintenance planning
3. Valuation for purchase/sales and tenancy agreements
4. Basis for reconstruction evaluation/planning

The Norwegian standard NS 3424 is a framework for consistent and objective evaluation of constructions. The survey is to be carried out by skilled personnel having the technical background within the field to be examined. All fields relevant to the purpose of the condition survey should be covered.

The result of the survey is a report that states the diagnosis and the probable future development of deterioration and an optional cost estimate – hence NS 3424 consists of the following main phases leading to the result as shown in Fig.1:

- Definition of the task
- Planning
- Examination
- Evaluation
- Reporting

2.1 The survey

The survey itself is based on a selected reference level and conducted in the main phases: registration, evaluation and reporting – leading to certain recommended actions

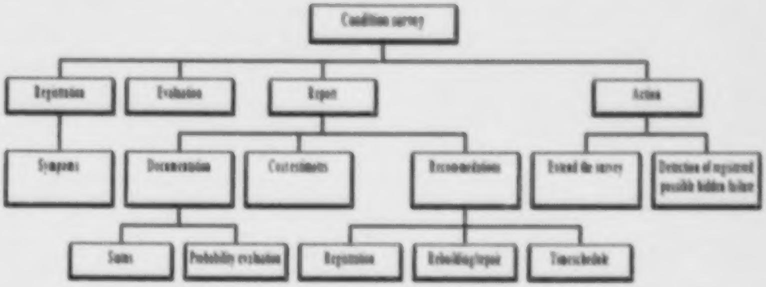

Condition survey
Registration
Evaluation
Report
Action
Symptoms
Documentation
Cost estimates
Recommendations
Extend the survey
Detection of registered possible hidden failure
Status
Probability evaluation
Registration
Rebuilding/repair
Timeschedule

Fig 1: Overview /structure of the condition survey

2.1.1 Registration

By future use of portable computers as "IBM's Wearable PC" and utilising positioning system in addition to voice control and high speed wireless networking one should be able to speed up the registration considerably, compared to manual registration at about 50 - 80 m2 per hour (Haugen 1988). There are three levels of registration/examination as defined in the standard.

- Level 1 (rough): Condition registration of a general character consisting of visual observations, if necessary combined with simple measurements.
- Level 2: Condition registration of a general character, but more exhaustive and detailed than level 1. It includes examination of supporting data, e.g. drawings, specifications and other documentation. When required due to symptoms or purposes more extensive registrations or measurements should be carried out to establish the construction and condition of the item.
- Level 3 (detailed): Condition registration of a special character that normally only includes specific items (building elements, construction elements, work sections) or specific problems. Such condition registration implies the application of especially accurate measurement or test methods and, if appropriate, laboratory testing

2.1.2 Condition registration

The registration consists of examination and recording at three different levels - from visual control, level 1 - to rigorous and punctilious testing, level 3.

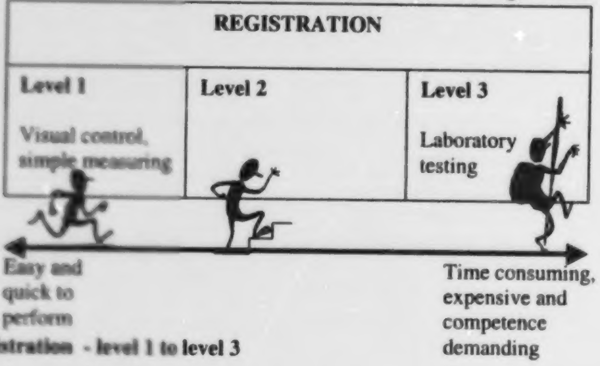

REGISTRATION
Level 1
Visual control, simple measuring
Level 2
Level 3
Laboratory testing
Easy and quick to perform
Time consuming, expensive and competence demanding

Fig. 2: Registration - level 1 to level 3

The condition is expressed by means of condition degrees from 0: no symptoms - to 3: strong symptoms (also includes collapse and malfunction). The condition degree is evaluated from one or more individual symptoms or on an overall evaluation of a set of symptoms.

2.1.3 Actions

The recommendations of actions are evaluated from the interaction between consequences and probability, defined as Risk. Recommended actions are specified and given priority in accordance with the purpose of the survey. A flowchart for actions is shown in Figure 3. Examples of actions are:

- Expand the condition survey
- Detection of registered possible hidden failures
- Elimination of registered failures
- Prevention of failures

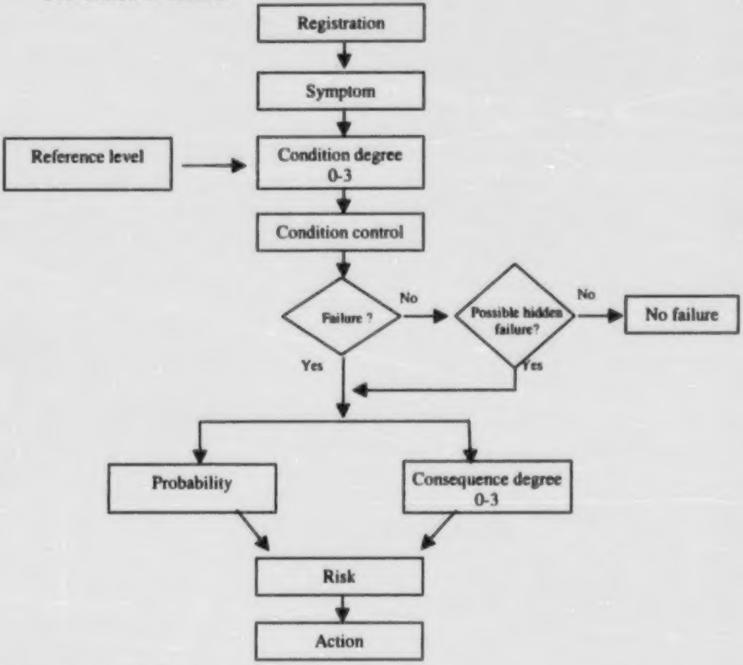

Registration
Symptom
Reference level
Condition degree 0-3
Condition control
Failure ?
No
Possible hidden failure?
No
No failure
Yes
Yes
Probability
Consequence degree 0-3
Risk
Action

Fig. 3: Flow chart for actions

2.1.4 Consequences

The consequences are expressed by means of consequence degrees and types. Four consequence degrees with the following main significance are to be used from degree 0: no consequences - to degree 3: serious consequences in addition of describing types as: safety (e.g. load-bearing capacity, fire safety), health environment (e.g. air quality, noise level), aesthetics (e.g. surfaces), economy (e.g. maintenance, renovation)…

2.1.5 Risk

The risk associated with a building element, construction element or work section is determined by the probability, based on the examiners opinion, that a non-acceptable condition (failure) or situation will occur or further develop, and the resulting consequences. The probability for increasing condition degree and the resulting consequence should be evaluated following two cases:

- Condition degree 0 but with registered failure or possible hidden failure.
- Condition degrees 1, 2 or 3.

The risk should be specified as low, medium, or high. The consequences that have been used as a basis for the specification of risk should be identified. Figure 4 visualises the coherence between consequences and probability as defined in the standard.

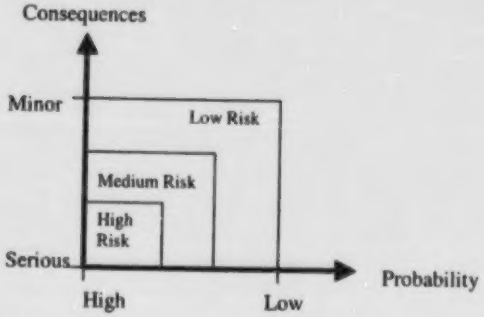


Fig. 4: Risk as result of probability and consequences

3 Planning ahead

Results from condition surveys can serve as a basis in budgeting for rebuilding and/or maintenance. In order to keep an effective pace and minimise the costs, it is important to keep the survey as simple as possible, without neglecting crucial information. The managers own staff provided some method-education and training can easily do level 1 registration. Level 1 registration can be planned as a routine once every second year to identify where to emphasise the effort in further diagnosis and action. However, in case of more extensive survey, one should make sure the competence involved is sufficient to rely on the result. In this case it would often be wise to get external help – making the survey visible on the budget and therefore demanding a strategy for how to deal with this issue.

3.1 Rebuilding

It is a well-known fact that the user requirements, illustrated in figure 5 (and public demand as ventilation etc), are constantly developing towards increasing levels.

It is not uncommon in technically dominated projects (e.g. hospitals) that the building is inadequate before hand-over – and rebuilding is immediately initiated.

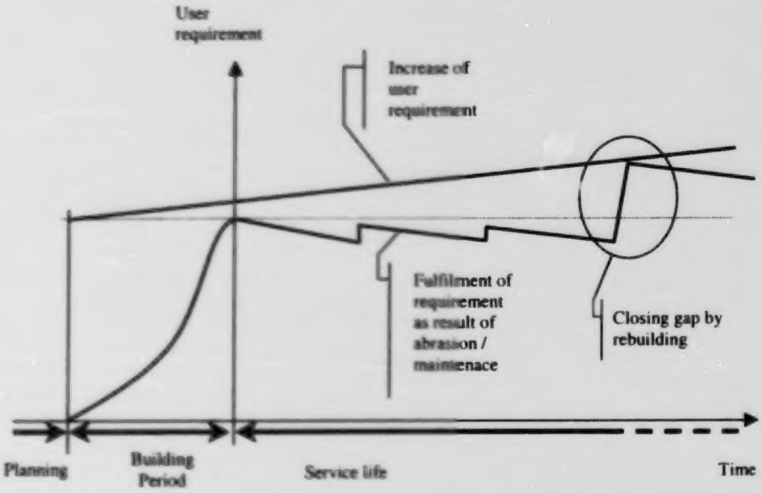

User requirement
Increase of user requirement
Fulfilment of requirement as result of abrasion / maintenace
Closing gap by rebuilding
Planning
Building Period
Service life
Time

Fig. 5: A building development of requirement fulfilment over time

In case of major rebuilding it is essential to have insight in what it might lead to of additional necessary changes and the cost of the operation. Rebuilding contractors have a saying: the more you tear down – the more you will have to tear down

3.2 Maintenance planning

As the building enters the phase of service life, maintenance costs tend to be systematically underestimated, and therefore resulting in accumulating deterioration and accelerated decreasing value. The typical need for maintenance is altering year by year due to different element service life and need for minor rebuilding to meet altered user demands. Especially regarding public buildings, it can be difficult to obtain sufficient means to obtain proper maintenance. One should aim at making the budgeting process predictable for the politicians to minimise the reluctance for spending money on purposes from which they don't see concrete results.

As a basis for yearly budgeting, one should calculate the estimated total maintenance and rebuilding costs for each building in the portfolio during service life. These total costs should then be subject to a calculation according to the annuity system. Such calculations are done by various consultants and are easily available for a number of types of buildings categorised by activities.

The actual maintenance planning can be done by once a year collecting requirements from users and a systematic registration done by skilled personnel. The maintenance budget can be divided into three categories: Planned maintenance, unforeseen/damage, and a reserve. Needs and requirements are to be prioritised within "planned maintenance" In this way it is possible to gain flexibility in planning and performing the maintenance during service life, and still, in great comfort for owners and politicians, the spent amount of money will be predictable.

The maintenance has to be monitored over time, and the resulting cost over time can serve as basis for benchmarking and estimating future costs.

3.3 Budgeting

A recommendation is to perform a three step budgeting - taken into account that the cost of having own workers compared to contracting external labour is of little significance (Hasvik and Haugen 1993):

Update the accumulated need over a period of time based on how severe the damages are.

Gather the need for funding by calculation based on cost per square meter per building type, and then reduce this amount by funding already raised on related areas.

Distribute the available amount (minus a reserve and an unforeseen - sum) by prioritising registered entries.

If the backlog is substantial in relation to obtainable funding, the owners must be notified of the need for extra funding. The backlog could today be expected to be from \$40-50 per m^2 (Haugen 1995) – roughly calculated from 1989 to \$146 per m^2 (Sveen and Holtet 1999)

In order to avoid confusion and double use of the same money one should cultivate the entries in the budget so only one person has the need for a selection of entries in order to carry out his/hers tasks.

In short: Budgeting by predicted yearly cost according to the annuity system for maintenance over the service life. Actual planning and performing due to registration.

3.4 Prioritising

It is not likely that the funding is sufficient – the needs have to be prioritised. By using the registered consequences by not fulfilling the needs in combination with weighed types of consequences, one will obtain a score per registered need, and a suggested prioritising by just sorting the scores. The weighting will reflect the maintenance policy.

Table 1: Key for prioritising and time planning

	Safety	Indoor climate	Aesthetics	Economic/ accelerating damage	User requirements	Authorities demands			
Weight	5	1	1	5	2	10	Scores	cost	Year

One can assume that next year's funding roughly matches this year's funding, and reserve one half for the needs one can not afford this year, one third of this year's funding the following year – and so forth. For registered needs not subjected to a condition survey – some sort of adapted Delphi approach (Linstone and Turoff 1975), suitable for the current organisation, is to be recommended for determining the consequences.

3.5 Probabilistic approach

In order to achieve a reliable plan and minimise the reserve needed, it is possible to utilise probabilistic methods given the assumption that the maintenance tasks are stochastically independent. This is formalised in a method mainly meant for management: "the step-by-step" principle (Klakegg 1993) and is a variant to the Delphi approach (Linstone and Turoff 1975).

3.5.1 The step-by-step principle

The step-by-step principles is dealing with uncertainty by identifying the most uncertain factor in the project and narrowing down the uncertainty by systematic detailing and recalculation (Klakegg 1993). The method is based on workgroups and subjective triple estimates.

A workgroup can be established from the maintenance staff, and they can brainstorm on cost estimating each maintenance task.

Other benefits of creating the workgroup from the staff in addition to a presumable better cost estimate, is ownership to the tasks to be performed the following year, and a valuable input in prioritising the tasks.

3.5.2 Triple estimate

This is a subjective approach and the quality is highly depending on the participants. They are supposed to estimate three values per subject:

- The minimum estimate
- The maximum estimate
- The expected estimate

These estimates consist of skilled estimates and intuitive guesses - "guestimates" or "hunch evaluations" The main problem in this process consists of difficulties in estimating the extreme values – meaning one is dealing with a group of experts – and experts tend to be sure of the outcome. One should emphasise on estimating the worst and best possible case.

3.5.3 Calculation

The Erlang distribution (a special case of the Gamma distribution) with k=10 is found to produce reasonable results representing the subjective estimates in the step-by-step principle.

The formulas presented here are based on the minimum estimate equals the 1% quantile and the maximum estimate equals the 99% quantile. Since the extreme values can be difficult to estimate (one of a hundred), it could be wise to rather aim at the 10% and 90 % quantile - one of ten. The formulas would then be slightly different, but the principle remains the same.

The statistical expected value f and the standard deviation can be calculated (Austeng and Hugsted 1995) from:

$$f = \frac{l + 2.95 \cdot m + h}{4.95} \qquad (1)$$

$$\sigma = \frac{h - l}{4.6} \qquad (2)$$

Where

l = minimum estimate (low), here 1 % quantile
m = expected estimate (medium)
h = maximum estimate (high), here 99 % quantile

The expected value and the variation (= σ^2) is to be calculated for each entry. When a number of independent elements of reasonably uniform size are calculated, one can assume the probability density function to be normal distributed, this means that the sum of variation per element adds up to the total variation for all elements.

Further – by using standard functions – one can select a level of certainty and calculate the cost of this level – or the other way around – select a cost and calculate the level of certainty for not overstep this limit.

By definition the element rating the top of variations are the most uncertain.

Special tools are developed for this calculation, but use of a spreadsheet for this task is strongly recommended.

4 Conclusion

The method described in the Norwegian Standard NS 3424 " Condition survey for construction works" is an available tool for revealing the status and producing documentation of the built environment.

The facilities manager's own staff can routinely do level 1 registration. Status, need for repair – can be used in conjunction with long term maintenance planning and prediction of additional work in rebuilding planning.

Maintenance budgeting should aim at predictable costs using the principle of annuity over service life per building type.

Prioritising by utilising the obtained consequence degree combined with weighed types of consequences.

Cost estimating can be improved by means of probabilistic methods utilising hunch evaluations and a "step-by step" principle/ Delphi approach.

5 References

Austeng, K. and Hugsted, R.(1995) *Trinnvis kalkulasjon*, Norwegian University of Science and Technology Dept. of Building and Construction Engineering, Trondheim, Norway (In Norwegian)

Hasvik, J and Haugen T. (1993) *Effetkiv forvaltning drift og vedlikehald av universitetsbygninger: Samlerapport frå prosjektet dataassistert bygningsforvaltning*,Civil and Environmental Engineering, Trondheim, Norway. (In Norwegian)

Haugen T. (1995) *Behovet for oppgradering av bygg og installasjoner : utfordringer i fremtiden*, Byggherren p. 16-19, Oslo, Norway. (In Norwegian)

Haugen T. (1988) Condition surveys with respect to automated facilities management systems, Civil and Environmental Engineering, Trondheim, Norway.

Klakegg, O.J. (1993) *Trinnvis - prosessen*, Dept. of Building and Construction Engineering, Trondheim, Norway. (In Norwegian)

Linestone H.A and Turoff M. (1975) *The Delphi Method: Techniques and Applications*, Addison-Wesley

Sveen T.E and Holtet Harald (1999) Preliminary report: *FoU Nøkkeltall prosjektet: Utarbeiding og bruk av nøkkeltall*, Multiconsult AS, Oslo, Norway. (In Norwegian)

The Norwegian Council for Building Standardisation, NBR (1995), *Norwegian Standard NS 3424*, Condition survey for construction works, Oslo, Norway. (In Norwegian)

156 A COMPUTER-AIDED PRIORITISATION FRAMEWORK FOR PLANNED MAINTENANCE MANAGEMENT

Q.P. Shen

The Hong Kong Polytechnic University, Kowloon, Hong Kong

Abstract

The mismatch between maintenance budgets and the ever-increasing maintenance needs of public buildings is a worldwide problem. As a result, many public buildings are deteriorating. Although it is unlikely to completely overcome this problem without an injection of further resources, it is possible for maintenance managers to improve the situation by ensuring that the best solution in terms of "value for money" is achieved in the planned maintenance programme. A computer-aided maintenance plan that is based on rational assessment of priorities and up-to-date knowledge of the condition of the property stock will help to ensure the best use of available resources. This paper presents the results of a major research project undertaken at the Hong Kong Polytechnic University. It focuses on the development of a multi-attribute prioritisation model by using the analytic hierarchy process to assign weightings to selected criteria for maintenance priority setting, followed by a description of the computer-aided prioritisation framework that implemented the prioritisation model. The framework is simple in practice and flexible from a management point of view, which empower maintenance managers to make more objective and rational decisions.

Keywords: Planned maintenance, computer-aided prioritisation, and public buildings.

1 Introduction

In the current economic climate, maintenance budgets for public buildings are unlikely to meet the ever-increasing maintenance need (Audit Commission, 1988). There is a pressing need to develop a framework within which maintenance can be prioritised rationally and limited resources can be allocated more wisely to achieve best value for money (Audit Commission, 1993).

Durability of Building Materials and Components 8 (Volume Three). *Edited by M.A. Lacasse and D.J. Vanier*. Published in 1999 by NRC Research Press, Ottawa ON K1A 0R6, Canada. ISBN 0-660-17742-0

Although it is unlikely to solve this problem completely without an input of further resources, it is possible to improve the situation by ensuring that the best solution in terms of "value for money" is achieved in the maintenance programme. A maintenance plan that is based on a rational assessment of priorities and up-to-date knowledge of the condition of the property stock will help to ensure that difficult long-term decisions are not outweighed by short-term considerations (Shen et al, 1998).

It is clear that increasing pressure is being brought to bear on the resources available for maintenance management and the setting of priorities has always been a problem for property managers who need to take a number of factors into consideration during the prioritisation process. The techniques in assessing "value for money" for planned maintenance are not robust and the resources for addressing the problem have become increasingly scarce (Spedding et al, 1994). Decisions concerning the use of resources on planned maintenance are normally based on qualitative assessment, containing a large amount of subjective elements which can lead to inadequate spending on repairs and maintenance, particularly for strategic work. Although senior staff are aware of the benefits of setting up priorities, little effort has been put into the development of a systematic approach of prioritising work by drawing upon maintenance databases and factors which often influence the decision-making process in planned maintenance.

The objective of the research undertaken at the Hong Kong Polytechnic University is to improve planned maintenance management of public buildings in terms of "value for money" by setting up a viable prioritisation model that takes into account of factors and issues which managers have to consider before decisions are made. A mathematical model has been developed for the priority setting process in an effort to connect the factors identified with quantitative data from condition surveys. This model provides a method of ranking maintenance and repair proposals on the basis of agreed criteria, in the knowledge that the application of common standards would reduce the subjective element that has featured so largely in maintenance decisions.

2 The practice of maintenance prioritisation in Hong Kong

In Hong Kong there are two government departments with large building stocks to look after - the Architectural Services Department (ASD) and the Housing Department. For the purpose of maximising the use of resources and good management, each of the above two departments has its own way of maintenance prioritisation.

The Property Services Branch (APB) of the ASD holds responsibilities for the construction and maintenance of all sorts of government properties in Hong Kong. The types of buildings taken care by APB include government offices, hospitals, clinics, police stations, fire services station, post offices, prisons, laboratories and workshops. In 1996/1997, the APB was responsible for maintaining 21.9 million m^2 of floor area, in more than 68 government departments. The overall expenditure was in the order of HK$570 million and the total number of work orders was around 200,000 in 1997. APB has a condition-related building maintenance programme. Its essence is to plan for or accept the possibility of restricted maintenance as a result of fiscal stress. The concept is simple and it can be described as follows:

The technical need of buildings is established through cyclic condition surveys. A priority system reflects stated policy in standards of maintenance for different types of buildings, usage of parts of buildings, health, safety and legal requirements. It is employed to rate the condition related maintenance proposals. Work items in projects are selected according to their priorities until the allocated funds are fully committed.

This method produces a budget relating real physical needs to funds available - a Needs Budget. Regular update of condition will gradually elevate deteriorating items or elements to a high priority to secure funds. The result of this approach is that APB can: (1) justify a budget - APB knows what work must be done and can explain to the administration the effect of not proceeding; (2) tailor the works programme to the funds allocated - in the event that the actual allocation does not reach the same value as the justified Needs Budget, APB will ensure essential works (high priority projects) are undertaken; and (3) record condition of buildings as a central source of information - condition is reflected in the on-site condition survey results, recorded in computers.

The Housing Department has a stock of 870,000 public flats, and some 3million m^2 of commercial and other facilities. Its budget represents 2% of Hong Kong's GDP. Housing 3.2 million people, it is "one of the world's largest home-makers". Besides public houses, the Department also managed a large number of auxiliary public buildings including 230 schools, 205 kindergartens, 75 nurseries, 57 libraries and study rooms, 568 welfare and amenity premises in public housing estates by the end of 1995 (Bates, 1996).

Each year the Department makes 200,000 repairs to public housing and home ownership estates. It has spent HK$4 billion in improvement and maintenance and the total expenditure would increase to HK$23 billion for the next five years from 1995. Between 1987/88 and 1994/95, the department has spent HK$1.7 billion on structural repair, representing 15.6 per cent of the total expenditure on maintenance.

The Housing Department has a rigorous and complicated survey and planned maintenance programme called CARE, which is the acronym for Condition, Appraisal, Repair and Examination, involving inspections inside every one of its 800,000 flats every 18 months and a thorough external review at least every six years. The concept is to systematically deal with maintenance and improvement of each public housing block by first carrying out a condition survey and then appraising the findings and arranging for works to be carried out in an intensive repair period of about 2 years. Tenants would be able to enjoy a low breakdown and "quiet" period of 4 years and an improvement in maintenance standards. The quiet period is also called examination period during which building condition data would be collected for the next CARE cycle.

Guidelines are developed for determining the priorities of the estates in the CARE programme. The priorities are as follows in descending order: (1) work necessary to maintain the safety of persons; (2) work necessary to keep property habitable (e.g., by reason of hygiene, security, electrical and water supply); (3) work necessary to keep buildings operational; and (4) work necessary for the appearance of the property, the provision or upkeep of non-essential services or facilities.

There are two serious problems associated with the above practice. Firstly, the decision-making process is not clear, it is difficult to tell why and how a surveyor assigns a certain priority to a particular maintenance item, subjective elements can be introduced very easily into the process. Secondly, since budgets for maintenance are normally significantly less than the real needs, the cut-off line can easily fall somewhere in the middle of a priority category, which creates a very difficult task for the maintenance managers to differentiate maintenance items in the same category.

3 The AHP-based multi-attribute prioritisation model

This multi-attribute prioritisation model was first introduced by Spedding, Holmes and Shen at the University of West of England (1994), based on a comprehensive study of the current practice of planned maintenance prioritisation in British local authorities and various existing prioritisation methods. It was further developed by Shen et al (1998) at the Hong Kong Polytechnic University, by using the Analytic Hierarchy Process (AHP) to assign weightings to selected prioritisation criteria on a quantitative basis. The method is straightforward from the practical point of view and flexible from the management point of view. It also increases client/user satisfaction through their participation in the more transparent prioritisation process.

As shown in Fig. 1, a number of major factors are normally considered by maintenance managers in the process of setting priorities for planned maintenance.

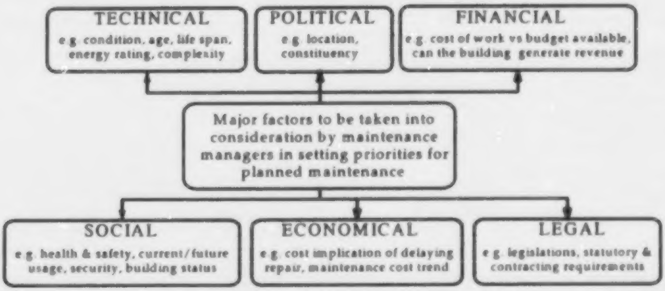

TECHNICAL
e.g. condition, age, life span, energy rating, complexity
POLITICAL
e.g. location, constituency
FINANCIAL
e.g. cost of work vs budget available, can the building generate revenue
Major factors to be taken into consideration by maintenance managers in setting priorities for planned maintenance
SOCIAL
e.g. health & safety, current/future usage, security, building status
ECONOMICAL
e.g. cost implication of delaying repair, maintenance cost trend
LEGAL
e.g. legislations, statutory & contracting requirements

Fig. 1: Major factors for maintenance prioritisation (Spedding et al, 1995)

Within the prioritisation model, these factors will be treated as priority setting criteria and weighting will be assigned to each criterion according to its relative importance. Every maintenance work identified during a condition survey will be measured and a score will be given in respect of each criterion selected earlier. Suppose n criteria $C_1, C_2, ..., C_i, ..., C_n$ are used in the prioritisation process, their relative weights are $W_1, W_2, ..., W_i, ..., W_n$, and work j was scored $S_{j1}, S_{j2}, ..., S_{ji}, ..., S_{jn}$ in respect of criteria $C_1, C_2, ..., C_i, ..., C_n$. The priority index S_j for job j can then be calculated by using the following formula:

$$S_j = S_{j1}*W_1 + S_{j2}*W_2 + ... + S_{ji}*W_i + ...+ S_{jn}*W_n .... \quad (1)$$

Details regarding the selection of prioritisation criteria, the determination of their weightings, and the scores given to a maintenance work with respect to each criterion will be described in the following section.

4 The computerised implementation of the proposed model

Because of the large amount of complicated calculations involved in the above model, it is essential to use a computer programme to assist its implementation in practice. It was also found by Holmes and Shen (1994) that where formal computerised prioritisation methods are not yet in use, maintenance managers have the difficult annual task of confirming or amending the priorities of many thousands of work items, initially given by individual surveyors. The following sections describe the computerised implementation of the model.

4.1 Selection of criteria for maintenance priority setting

The criteria used in the prioritisation process and their weightings may be different among different organisations. These reflect differences between their maintenance objectives, policies and practices. The following commonly used criteria have been identified in setting up maintenance priorities (Holmes and Shen, 1994), which can be selected from the computerised programme:

(1) **Building Status (BS):** The relative importance of the building (where the defective element is examined) compared with others, in terms of function, current and intended future usage, e.g. an infant school might have a higher status than a leisure building.

(2) **Physical Condition (PC):** The physical condition of the defective element being examined, and its possibility of breakdown or failure, e.g. elements in very bad conditions would be given higher priorities than those in fair conditions.

(3) **Importance of Usage (IU):** The importance of the functional unit (in relation to other units within the same building) where the defects are situated, e.g., the reception area would be more important than storage rooms.

(4) **Effects on Users (EU):** The effects of breakdown or failure of the defective element(s) on the occupants and users of the building (including staff and members of the public), e.g. health and safety problems are more important than aesthetic problems.

(5) **Effects on Fabrics (EF):** The cost implication of breakdown or failure of the defected element(s) on maintaining the overall condition of the building fabric and building services, e.g. if a defective roof is not repaired promptly, the eventual cost would be higher due to possible damages to other building elements.

(6) **Effects on Service Provision (ESP):** The cost implication of breakdown or failure of the defected element(s) on the provision of services the building is used for.

In addition to the standard criteria listed above, some special criteria, such as legal requirements, special maintenance policies, and pressures created from day-to-day maintenance also need to be considered when assessing maintenance priorities. These special criteria sometimes override the standard criteria. For instance, a low priority could be assigned to a maintenance job according to the standard criteria, however, because the work is required to comply with a conservation order, a very high priority will be assigned to keep it in the next maintenance programme.

4.2 Determination of weightings for maintenance criteria by using AHP

AHP was developed by Saaty (1990) to help individuals and groups deal with multi-criteria decision-making problems. By incorporating both subjective and objective data into a logical hierarchy framework, AHP provides decision-makers with an intuitive approach to evaluate the importance of every element of a decision through a pair-wise comparison process, allowing them to structure complex problems in the form of a hierarchy. A hierarchy has at least three levels: the goal, the criteria and the alternatives. In our model, AHP was used only to determine the relative importance of the criteria in meeting the goal. Fig. 2 illustrates the flow diagram for this process.

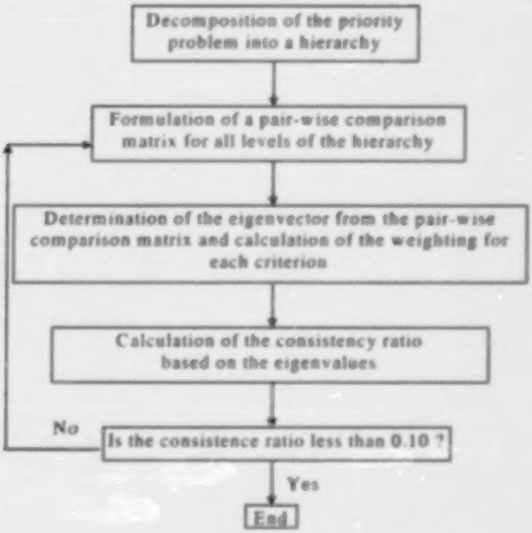

Decomposition of the priority problem into a hierarchy
Formulation of a pair-wise comparison matrix for all levels of the hierarchy
Determination of the eigenvector from the pair-wise comparison matrix and calculation of the weighting for each criterion
Calculation of the consistency ratio based on the eigenvalues
No
Is the consistence ratio less than 0.10 ?
Yes
End

Fig. 2: The AHP-based multi-attribute prioritisation process

Formation of a decision-making hierarchy

The prioritisation problem can be broken down into a hierarchy of interrelated decision elements as shown in Fig. 3. Level 1 describes the objective of the decision-making problem. Level 2 contains factors that are perceived as important attributes to achieve the objective described in level 1. In theory, this process can be extended to include many levels. Factors listed at each level are perceived as important attributes that affect attributes at the upper level. For simplicity reasons, the number of levels in Fig. 3 has been restrained to two. Managers with decision-making responsibilities will provide information within the hierarchy.

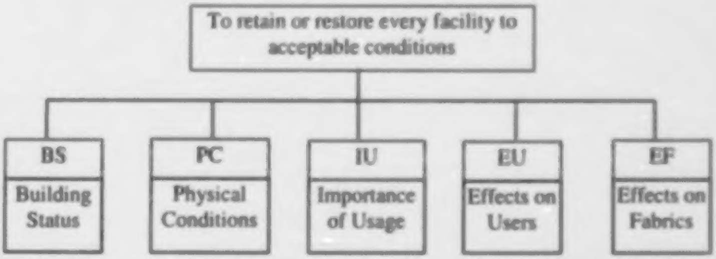

To retain or restore every facility to acceptable conditions
BS
Building Status
PC
Physical Conditions
IU
Importance of Usage
EU
Effects on Users
EF
Effects on Fabrics

Fig. 3: Hierarchy for prioritisation of planned maintenance of public buildings

Formulation of a pair-wise comparison matrix

In order to decide the relative importance of one criterion versus another, a number of pair-wise comparisons between the criteria with respect to the goal of the hierarchy have to be made. Decision-makers are asked to make judgements for the comparisons. Each comparison involves assessing relevant importance of one factor over the other factor with respect to the goal in a ratio scale. Table 1 shows commonly used scales. The comparison is represented in a pair-wise comparison matrix. If there are *n* items to be compared for a given matrix, a total of $n(n-1)/2$ judgements are needed. The eigenvector of the matrix provides a priority ordering and the eigenvalue gives a measure of the consistency of judgement. A consistency ratio of less than 0.10 is acceptable, otherwise changes should be made to the original judgements made by the maintenance manager.

Table 1: Fundamental ratio scale in pair-wise comparison (Source: Saaty, 1990)

Intensity of importance	Definition	Explanation
1	Equal Importance	Two activities contributes equally to the objective
3	Weak importance of one over another	Experience and judgement slightly favour one over another
5	Essential or strong importance	Experience or judgement strongly favour one over another
7	Very strong or demonstrated importance	An activity favoured very strongly over another; its dominance demonstrated in practice
9	Absolute importance	The evidence favouring one activity over another is of the highest possible order of affirmation
2, 4, 6, 8	Intermediate values between adjacent scale value	When a compromise in judgement is needed
Reciprocals of above nonzero	If activity *i* has one of the above nonzero numbers assigned to it when compared with activity *j*, then *j* has the reciprocal value when compared with *i*.	A reasonable assumption
Rationales	Ratios arising from the scale	If consistency were to be forced by obtaining *n* numerical values to span the matrix

As shown in Table 2, by answering question "with respect to the given criterion, what is the importance of factor *i* over factor *j*?", the pair-wise comparison matrixes are formed. For instance, if a decision-maker believes that "safety" is absolutely more important than "aesthetics" with respect to the goal, a value of 9 to "safety" expresses this judgement. If "effects on users" are moderately more important than "effects on fabrics", a value of 3 can be assigned to "effects on users". The weightings in the last column of the table are calculated based on the method introduced in the next section.

Computation of priorities and consistency ratio

From the pair-wise comparison matrix, the eigenvector and the maximum eigenvalue could be calculated by using the right eigenvector method. The eigenvector provides the weightings of the criteria while the maximum eigenvalue is used to obtain a measure of the consistency of the judgement. The right eigenvector method is the most widely used method, in which the general eigenvector equation $AW=\lambda_{max} W$ is used, where A is the pair-wise comparison matrix, $W=(W_1\ W_2\ W_3\ W_4\ W_5)^T$ is the vector of actual relative weightings of the criteria.

Table 2: Pair-wise comparison matrix

With Respect to Goal	BS	PC	IU	EU	EF	Weighting
BS	1	1/3	3	1/4	2	0.123
PC	3	1	5	1/2	4	0.280
IU	1/3	1/5	1	1/9	1/3	0.043
EU	4	2	9	1	6	0.471
EF	1/2	1/4	3	1/6	1	0.083

A Consistency Ratio (CR) will be calculated to measure the consistency in the pair-wise comparison: CR= CI / RI, where CI is called consistency index defined as $CI= (\lambda_{max} - n) / (n - 1)$, RI is the random consistency index obtained by averaging the consistency index of a randomly generated reciprocal matrix from a scale of 1 to 9. The value of RI could be obtained from Table 3.

Table 3: Value of random consistency index (Saaty, 1990)

Matrix Size	1	2	3	4	5	6	7	8	9	10
RI	0.00	0.00	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49

Based on this method, and by using a commercially-available computer software called "Expert Choice", the results for the matrix shown at the previous section are as follows: $W=(W_1\ W_2\ W_3\ W_4\ W_5)^T = (0.123\ 0.280\ 0.043\ 0.471\ 0.083)^T$, $\lambda_{max} = 5.10$, CI=(5.10-5)/(5-1)=0.025, CR=0.025/1.12=0.02.

4.3 Assigning scores for maintenance works in respect of each criterion

Having selected the criteria for prioritising maintenance works and determined their weightings, it is necessary for building surveyors to assign scores to maintenance items in respect of each criterion, and to calculate the priority indexes based on formula (1). A database programme has been designed specifically for this purpose.

In order to ensure consistency, we have designed detailed guidelines on assigning scores to maintenance works for surveyors. For example, in respect criterion "physical condition", a score of 5 will be given to the item under examination if it is in a very bad condition and requires immediate attention; a score of 4 will be given if its overall condition is bad but does not need immediate attention. In order to avoid district building surveyors compete with each other by giving higher scores to the maintenance items they are looking after, if necessary, the chief building surveyor in-charge can keep the weightings confidential, so that building surveyors do not know which scores they should increase to have the highest possible effect on the priority.

4.4 Testing of the AHP-based multi-attribute prioritisation model

The model for prioritisation of maintenance work has also been tested with real data provided by the Architectural Services Department in Hong Kong. During the test, a total of around 60 maintenance items were picked up from the condition survey among schools. The chief building surveyor from the participating organisation was then asked to do a pair-wise comparison for selected maintenance criteria using the model, based on which the following weightings are calculated: BS=0.123, PC=0.280, IU=0.043, EU=0.471, EF=0.083.

In respect of each selected criterion, the chief surveyor gave a score for a maintenance item. A priority index (PI) was calculated for each item by using formula (1) as described earlier in this section. Based on the priority index, all the maintenance items were rearranged in a descending order of priority. Table 4 shows a small number of the 60 selected items with high priority indices. The PI for the first listed item, for example, is based on: 3x0.123+5x0.280+4x0.043+5x0.471+5x0.083=. The accumulated cost is used for placing a cut-off line among maintenance items to separate items in the current maintenance programme from those in the backlog.

Table 4: An example of modified multi-attribute prioritisation

Property	Functional Unit	Description of Defect	BS	IU	PC	EU	EF	PI
KT GTSS	Corridor	Mosaic tile flooring with patches	4	5	5	5	3	4.426
HH GPS	External Wall	Spalling concrete	4	4	5	5	4	4.375
HH GPS	Corridor	Spalling concrete at roof	4	4	5	5	4	4.375
KT GTSS	Boys Toilet	Flushing water of urinal splashing	4	5	5	3	4	3.943
HH GPS	G/F Glass Pane	Broken	4	3	3	5	2	3.827
KT GTSS	Biology Lab	Side benches rotten	4	4	4	4	2	3.766
KT GTSS	Boys Toilet	Hand basin detached from wall	4	5	2	3	4	3.736
KT GTSS	Boys Toilet	Door frame of a cubicle damaged	4	5	3	3	3	3.686
QE Sch	16 Nos Classroom	Repair to electrical installation	3	3	2	5	4	3.657
KT GTSS	Drawing Room	Door damaged	4	4	4	4	1	3.647
KT GTSS	Classroom 407	Door lock and hinges damaged	4	3	3	4	3	3.644
HMT GMS	Physics Lab	Ditto	4	3	4	4	2	3.594

The test indicated that by using the framework it was possible to speed up the priority setting process with increased transparency and reduced subjectivity. The results showed that although most of the maintenance items in the current programme appear at the top of the list, a few items in the current maintenance programme appeared near the bottom of the rearranged list. The main reason for these "low-score" items being included in the current maintenance programme was the fact that they satisfied some special criteria. For instance, according to this authority's policy, the 2nd phase of a project will be given a very high priority to put it in the next year's planned maintenance programme regardless its current condition and effects on users etc.

5 Conclusions

The computerised implementation of the AHP-based multi-attribute prioritisation model for planned maintenance was developed for organisations with large building stocks. Because the weighting of each criterion is of vital influence on the final prioritisation results, it is necessary to use a computerised programme to assist the complicated calculations in deciding the weightings for each criterion. This approach also improves client and end user satisfaction through improved transparency in the prioritisation process and their increasing awareness and participation of the process.

The computerised model is being refined for further implementation in a number of participating maintenance organisations. It is necessary to test the model further in two aspects: (1) to see how well building surveyors in Hong Kong respond to the modified method of data collection during their condition surveys or inspections, and (2) to further test the validity and weightings of the identified criteria.

Although the above method was mainly designed for the planned maintenance of public buildings, the concepts and principles could be easily extended to the private sector. In order to facilitate the testing of the model, a method of collecting data was produced. Guidelines for assigning scores to maintenance works have been prepared for surveyors to ensure the consistency in the scoring process, which is critical to the success of the new method. The documentation for data collection and procedures in using the computerised model is now ready for full testing in both the public and private sectors.

6 References

Audit Commission for Local Authorities in England and Wales (1988). Local Authority Property - A Management Handbook, HMSO.

Audit Commission for Local Authorities in England and Wales (1993). Adding Up the Sums: Schools' Management of Their Finances, HMSO.

Bates, R. (1996). The Evolution of Maintenance Management. Housing for Millions, The Challenge Ahead, Housing Conference by Hong Kong Housing Authority, 73-80.

Chan, K. (1993). Maintenance of Public Buildings. Property Services Branch (APB) of the Hong Kong Architectural Services Department (ASD), pp. 43-45.

Department of Education & Science (1985). Maintenance and Renewal in Educational Buildings - Needs and Priorities, Architects and Building Group, Design Note 40.

Holmes, R. and Shen, Q.P. (1994). An Analysis of Maintenance Prioritisation Practice in Local Authorities, The 10th ARCOM Annual Conference organised at Loughborough University of Technology, Leicestershire, UK, 14-16 September 1994, pp. 117-126.

Property Services Branch of the Hong Kong Architectural Services Department (1992). Paper One (Management of Maintenance: Third Wave Tactics), Hong Kong.

Saaty, T.L. (1990). The Analytic Hierarchy Process-Planning, Priority Setting, Resource Allocation, RWS Publications, University of Pittsburgh.

SCALA (1993). Maintenance Expenditure 92. Society of Chief Architects of Local Authorities, November.

Shen, Q.P., Lo, K.K., & Wang, Q. (1998). Priority setting in maintenance management of public buildings: a modified multi-attribute approach using AHP, Construction Management and Economics, Vol. 16, No. 6, pp. 693-702.

Spedding, A., Holmes, R. & Shen, Q.P. (1994). Prioritising Major Items of Maintenance in Large Organisations, RICS Research Conference "A Focus for Building Surveying Research", Salford University, December, pp. 123-131.

Spedding, A., Holmes, R. and Shen, Q.P. (1995): Prioritising Planned Maintenance in County Authorities, International Conference on Planned Maintenance, Reliability and Quality Assurance, Cambridge, UK, 6-7 April, pp. 172-178.

157 DETERIORATION PATTERNS FOR MAINTENANCE MANAGEMENT — A METHODOLOGICAL APPROACH

I.M. Shohet, Y. Rosenfeld, M. Puterman, and E. Gilboa
National Building Research Institute, Haifa, Israel

Abstract

Increasing demands are made on maintenance programs to provide versatile tools that will support maintenance strategies at different levels of service. One of the most important parameters affecting the efficiency of maintenance programs is the precision and reliability of the predicted service life of building components. The main objective of this study is to develop a methodology for the establishment of databases listing deterioration patterns of building and systems components based upon their actual condition monitored in-situ. The methodology integrates diagnostic tools into an analytical model and is sustained by a comprehensive field survey. The methodology was implemented at this stage on three types of exterior cladding systems: (1) stucco claddings; (2) ceramic tiles or mosaics; and (3) stone claddings. A preliminary field survey reviewed some 30 mechanisms of failures that may stem from: (a) Faulty design; (b) Poor quality of implementation; (c) Poor quality of materials; (d) Adverse climatic conditions (intensive UV or chlorides); (e) Adverse atmospheric conditions caused by air pollution; (f) Poor maintenance; (g) Intensive use. The methodology incorporates 3 steps: Identification of failures patterns, Determination of the actual condition point, and evaluation of the predicted service life.

Keywords: maintenance management, deterioration, service life, failure analysis, diagnosis, exterior claddings.

1 Introduction

There is a growing awareness world-wide of the importance of the maintenance of constructed facilities. This trend is an indication of the growing complexity of buildings, the increasing portion of systems in them, and the higher levels of service that are demanded by different types of owners - institutions, private owners, etc.

Durability of Building Materials and Components 8 (Volume Three). *Edited by M.A. Lacasse and D.J. Vanier*. Published in 1999 by NRC Research Press, Ottawa ON K1A 0R6, Canada. ISBN 0-660-17742-0

These raise ever-higher requirements of the life-expectancy models predicting the deterioration paths of various building components with a view to improving the effectiveness of the implementation of maintenance plans.

1.1 Rationale

Increasing demands are made on maintenance programs to provide versatile tools that will support maintenance strategies at different levels of service. The maintenance strategies used by Organizations differ from those preferred by owners of large stock facilities, the latter often requiring other levels of performance. Hotels and hospitals, for example, require that most the components in their utility facilities perform at the highest level and stipulate that they be replaced as soon as start to deteriorate. Owners of office buildings, on the other hand, may be satisfied with holding the facility at an "acceptable" level of service, in order to minimize the costs.

1.2 Objectives

The main objective of this study is to develop a methodology for the establishment of databases listing deterioration patterns of building and systems components. Such a methodology would enable the maintenance staffs to evaluate the life cycle of building components based upon their actual condition monitored in-situ. The goals may be defined as follows:

- Characterisation of deterioration patterns of different degradation mechanisms;
- Development of a systematic, practical procedure to determine the Service Life of building components based on their actual condition at a given time.

Due to the scope of the subject, the methodology was implemented at this stage on three types of exterior claddings: (1) Stucco, (2)ceramic claddings, (3) stone claddings.

1.3 Stages of development

The development process consisted of 5 sequential phases, as follows:

1. Field Survey;
2. Classification of deterioration mechanisms and typical failures;
3. Analysis of patterns of premature deterioration and failures;
4. Mathematical representation of deterioration mechanisms;
5. Development of a systematical model for determining the Predicted Service Life (PSL).

2 Background and review

The preliminary survey of existing methods revealed two main terms in the domain of Service Life Prediction: Failure, performance of building components, and methodologies to characterize the pattern of deterioration mechanisms.

2.1 Failures

Failure is defined as a condition in which a component does not meet the performance requirement of its designated use. This definition includes a wide range of sophisticated features such as minor visual faults in the component, and more severe serviceability problems such as excessive deformations, premature deterioration of materials, leaking roofs and facades, etc. (Feld & Carper, 1997).

There are two classical approaches to the characterization of failures:

- The "symptomatic" approach – This concept focuses on the results of the failure and the effects of the failure on the building in terms of cracking, peeling off, leakage etc. This approach does not involve an in-depth analysis of the failures.
- The "circumstantial" approach – This concept focuses on the failure itself and the mechanisms of degradation, the history of the building, and the major faults that led directly or indirectly to premature degradation.

The methodology here presented uses both approaches in the treatment of Predicted Service Life (PSL) of building components. The knowledge base of this methodology is sustained by an analysis of the numerous degradation mechanisms that were identified in the field survey, while the symptomatic approach is used to supply the user of the methodology with the classification of mechanisms of premature deterioration.

2.2 Models and methodologies for predicting the deterioration of building components

This section reviews some projecting methods for the evaluation of the service life of building components. These methods may be classified into *factorial*, *experimental*, and *empirical*, methods. The first category is based on a review of degradation factors and the determination of life expectancy based on multipliers. The second category makes use of in-situ tests or laboratory-accelerated degradation tests to evaluate the effect of a specific agent of deterioration. The third category is supported by a field survey of degradation factors followed by the systematic determination of the Life Cycle based upon ranking systems.

2.2.1 The AIJ method

In 1979 the Architectural Institute of Japan initiated research and development in the domain (Architectural Institute of Japan 1993). The methodology proposed by that institution falls under the factorial methods and is summed up in the following expression:

$$Y = Ys * A * B * C * D * E * F \tag{1}$$

where: Y – the predicted service life
Ys – the standard Service
A – the quality of the materials used
B – the quality of the design
C – the quality of implementation
D – Level of maintenance
E – Environmental conditions
F – General condition of the building

The deficiencies of this approach are:

- It requires in-depth studies of design, material, and implementation factors;
- It does not refer to the escalation or deceleration of deterioration over time.
- It does not define a systematic ranking of the service level.

2.2.2 The RILEM methodology

An integrative and comprehensive methodology based upon existing methods was suggested in (Masters, 1987). This method combines the experimental approach with diagnostic investigation. It consists of 5 phases:

1. Definition of user's requirements and of functional needs;
2. Preparation - Including identification of degradation mechanisms, sources of deterioration, and major indicators of premature degradation;
3. Pre-testing – Planning of accelerated deterioration tests;
4. Testing – Accelerated and continuous deterioration testing;
5. Interpretation and discussion – Prediction of Service life.

This approach combines experimental with diagnostic tools, and thus requires a wide knowledge and understanding of deterioration mechanisms.

2.2.3 Laboratory tests

This approach is demonstrated in (Searls &Thomasen, 1991; and Henriksen, 1995). It was proved to be adequate for cases in which the effect of a specific agent of deterioration is investigated. A similar approach is realized in accelerated deterioration testing. Its major disadvantage is the time and the financial resources required. It is thus cumbersome for use in maintenance management.

2.2.4 Physical and visual ranking of components performance

This method, implemented in (Shohet & Laufer, 1996), is based on a systematic evaluation of the physical and the visual degradation of building systems and uses a survey of multiple buildings of different ages and subjected to environmental conditions. The ranking system is composed of 5 levels, 1- representing total failure and 5 – high-performance components. This methodology emphasized the strong impact of environmental conditions on the life cycle of building components.

In (Hermans, 1995) the concept of the dependency between the Building components performance and the entire facility's level of service was treated with emphasis on the performance management of facilities.

The methodology described in the present paper synthesizes the factorial method with the systematic ranking of cladding components. This synthesis makes use of the advantage of the factorial methods (time saving), while employing a systematic ranking of performance levels.

3 Methodology

The development comprised 5 stages, which built an empirical basis and later a mathematical basis for the method:

1. Comprehensive field survey;
2. Systematic review of failures;
3. Characterization of 4 types of deterioration patterns;
4. Development of tables for identifying agents of deterioration and their effect on the life cycle of the component;
5. Integration of the paths of deterioration into the predicted life cycle through Life Cycle Limiting Coefficients.

3.1 Field survey

A preliminary in-depth field-survey was carried out at the beginning of this work. This tool aimed at the following objectives: (a) Survey of the methods of implementation; (b) Review and survey of the abundant mechanisms of premature deterioration in exterior cladding systems.

The field survey produced with the following conclusions:

- There exist some 30 major typical mechanisms of deterioration, which lead to failure due to premature degradation.
- 80% of these failures, of different levels of severity, appear within the first year after construction.
- 90% of the failures become visible not later than two years after construction.

Based upon these findings, the methodology aims at predicting the Life Cycle Expectancy of exterior claddings on the strength of an in-depth review of the faults, defects, and failures in exterior cladding components. Figure 1 shows a typical deterioration path of exterior cementitious stucco which in this case was caused by the lack of drip-edge at the top of a residential building. Figure 2 illustrates the concept of deterioration patterns evolved in this work (demonstrated in this particular case by a linear pattern). The main area (coloured dark grey) represents 80% of the population (of this deterioration mechanism) – exhibiting the standard pattern. The wider section represents a range under which we assume 90% of the population to fall.

A review of the causes of failure identified seven of the most frequent sources of premature deterioration in exterior cladding systems under study:
(1) Faulty design; (2) Poor quality of implementation; (3) Poor quality of materials; (4) Adverse climatic or atmospheric conditions (air pollution or intensive UV); (5) Adverse atmospheric conditions caused by air pollution; (6) Poor maintenance; (7) Intensive use.

3.2 Review of failures

The major agents of premature deterioration identified from the field survey were summarised as the basis for a systematic review of failures. Table 1 offers an example of such a review for cemetitious stucco. The agents of deterioration were first classified on the basis of symptomatic criteria such as cracking, peeling off, and decay. This classification was later amplified with files of descriptive photographs to assist the user in the verification of the features. These tables were then used as a basis for the establishment of a photo-ranking system for the determination of the Components Performance in Failure Condition (CPFC), as seen in Figure 3.

3.3 Determination of component performance in failure conditions (CPFC)

The next stage of development is the establishment of checklists for characterising the performance level of a component. This step is taken with the aid of photo-tables that visualise the condition of the component based on a scale of 0-100%. (Figures 1 and 3). 100% represents perfect condition with no deficiencies, 75 % represents the beginning of deterioration, 50% represents escalating developing deterioration and below 25% represents a condition of severe failure. This scale is used as a consistent tool for ranking the performance levels with numerous users. The CPFC expresses the impact of several factors on the service condition, and the durability of the component. However, in the ranking process we are not interested in the mechanisms but in the symptoms of deterioration. This makes the methodology friendly for multiple users who may not be experts in the in-depth analysis of the deterioration mechanisms. The tools used in the methodology contain tables for 30 mechanisms in 3 categories of exterior claddings (stucco, ceramics, and natural stone).

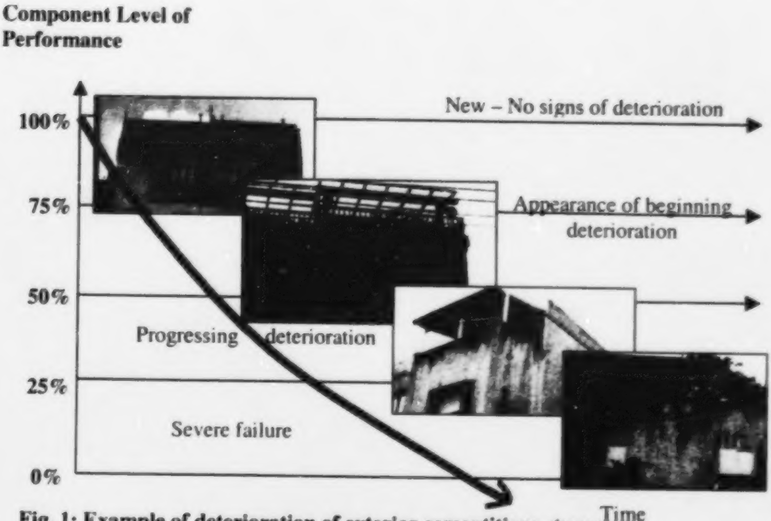

Component Level of Performance
100%
75%
50%
25%
0%
New – No signs of deterioration
Appearance of beginning deterioration
Progressing deterioration
Severe failure
Time

Fig. 1: Example of deterioration of exterior cementitious stucco

3.4 Deterioration patterns over time

The characterisation of deterioration patterns is perceived in this methodology as the focal tool for predicting the service life of components. The deterioration patterns are presented in graphs in which the independent variable is time, the dependent variable is the CPFC expressing the change in the level of service over time. The graphs (Figure 3) are sustained by a 2-stage analysis:

- Trends of deterioration patterns identified in the field survey. Analysis of mechanisms of deterioration, based on the identification of deterioration agents that were clearly detected.

Table 1: Example of checklist of deterioration agents in cementitious cladding

Failure Number	Type of failure	Deterioration agent
1	Change of colour and peeling off	Moisture due to irrigation
2	Leaking of corrosion from metallic fittings	
3	Graffiti	
4	Cracking and local peeling off	Corrosion and swelling of the reinforcement bars
5	Appearance of moisture and leaks in the vicinity of the top of the building (coping)	Faulty coping or lack of this component
6	Broken edges of columns, beams etc	Lack of protection on beams
7	Spots of moisture and absorption of water	sloping planes with porous materials
8	Degradation of stucco, crumbling and peeling off	Erosion due to wind
9	Horizontal or vertical cracking	Lack of expansion joints
11	Moisture spots, and stains around in-wall drainpipes	Cracks or disruptions in drainpipes
12	Development of Micro- organisms and cyanobacteria near edges of the building	Lack of drip edge and coping and development of moisture on the cladding
13	Horizontal and vertical cracking	Sinking of cantilever
14	Diagonal cracking	Differential sinking of foundations

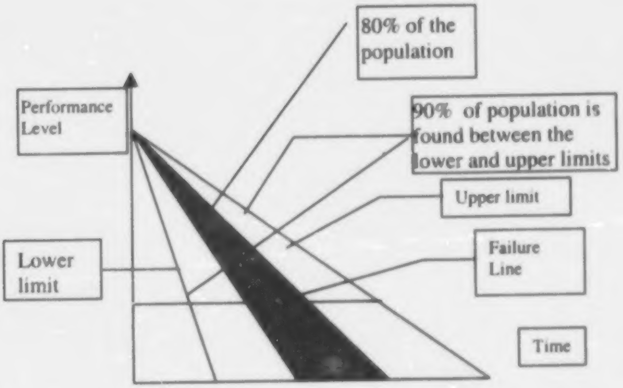

80% of the population
Performance Level
90% of population is found between the lower and upper limits
Upper limit
Lower limit
Failure Line
Time

Fig. 2: Schematic paradigm of deterioration pattern – linear deterioration pattern

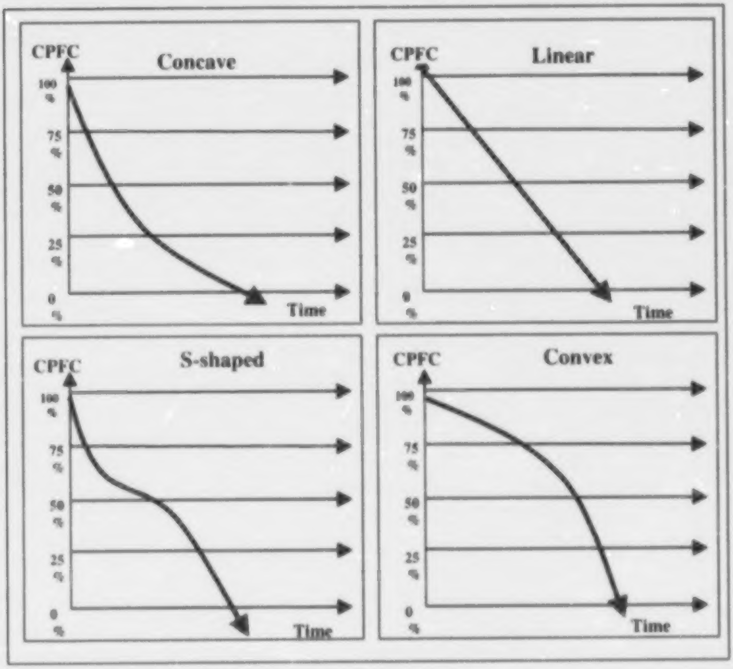


Fig. 3: Four typical patterns of deterioration paths

Four patterns of deterioration were defined (Figure 3):

1. Linear pattern – This pattern is typical in situations where a permanent deterioration agent exerts a continuous and consistent impact on the cladding. This pattern is manifested in the effect of erosion by wind, the decay caused by intensive UV radiation (on synthetic stucco), etc.
2. "Convex-Shaped" pattern – characterises physical or chemical phenomena, such as concrete shrinkage, that cause physical failure of the entire system of exterior cladding.
3. "Concave-shaped" pattern – represents the action of chemical and physical agents on claddings such as stucco and natural stone. Such impact appears in cases of microorganism or Cyanobacteria development on cementitious stucco and on natural stone. The difference between the cases is the pace of decay – fast in stucco, slower in stone.
4. S-shaped pattern – represents a deterioration mechanism that changes its intensity over time. The pattern appears when certain building details, such as coping or drip edge, are lacking, a situation that makes a visual impact shortly after the end of construction. Then the major mechanism becomes the physical reaction, which takes longer to affect the strength of materials. When that process ripens,

the deterioration accelerates, and its impact becomes visible. This pattern was characterized in the case of a drip edge lacking at the top of buildings.

3.5 Determination of the typical path of deterioration

The establishment of paths of deterioration provides a means for evaluating the presumptive service life for a specific deterioration mechanism (such as corrosion of reinforcement bars etc.). This stage is visualized in Figure 4. Provided that the age of the component and the CPFC (the one evaluated in the preceding stage) are known, the user determines the Actual Condition Point (ACP) for the specific deterioration mechanism. The user may check his evaluation by using the 90% range between the upper and the lower deterioration paths as defined previously (in Fig. 2). This step makes use of a form that helps the user to identify the *specific* deterioration pattern on the basic deterioration graph that had previously been identified. The deterioration patterns were derived from the ACP (Actual Condition Points) that had been gathered in the field survey. The deterioration path (thought to be the typical one) is extracted by the user through extrapolation from the curve between the starting point (Age 0, CPFC=100), and the Actual Condition Point (ACP). Following this step, it is possible to evaluate the Service Life for the Deterioration Path can be evaluated. This parameter then represents the Life Expectancy in the situation in which the specific agent is the only one affecting the component. The user must repeat this procedure for each deterioration mechanism identified in Stage 2 (3.2).

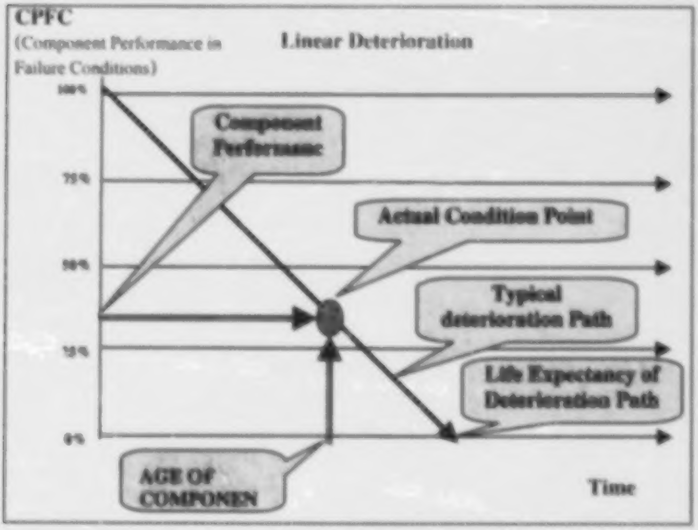


Fig. 4: Determining the typical path of deterioration

3.6 Determination of the predicted service life (PSL)

The model for calculating the Predicted Service Life is sustained by the factorial method combined with the evaluation of the CPFC (Component Performance in Failure Condition).

3.6.1 Evaluation of the standard life expectancy (SLE)

The parameter expressing the Life Expectancy of cladding systems, known as the Standard Life Expectancy, is based on findings of previous studies. It expresses the service life of the component along a normal aging path, in which there are no exterior adverse conditions, and no defects, such as inferior quality of materials, faulty design, or poor implementation are visible. These conditions represent ideal normal service conditions. The Standard Service life for the materials studied in this work include:

1. Cementitious stucco: 20 years;
2. Ceramic claddings: 25 years
3. Stone cladding: 40 years.

3.6.2 Determination of the influence coefficient (IC) for deterioration paths

The Influence Coefficient for a specific deterioration path expresses the partial effect of a specific deterioration agent in the comprehensive failure of the cladding system. The value of this coefficient ranges between 0 for degradation agents that do not affect the Predicted Service Life (for example the effect of UV on stone), and 1 for agents that strongly impact the PSL (corrosion of porous cementitious stucco in a marine environment). For example, the corrosion of reinforcement bars is given an IC of 0.6, while the deterioration caused by exterior mechanical damage to edges of ceramic tiles, referred to as a local deterioration agent, is given IC=0.25.

3.6.3 Determination of the Life Expectancy Limiting Coefficient (LELC)

The LELC is now calculated in order to quantify the effect of the specific deterioration path on the Predicted Service Life of the component. The LELC is based on the SLE, the IC, and the LEDP through the following expression:

$$LELCn = 1 - \frac{SLE - LEDPn}{SLE} * ICn \qquad (2)$$

Where,

LELCn – The Life Expectancy Limiting Coefficient for the nth deterioration mechanism;

SLE – the Standard Life Expectancy;

LEDPn – the Life Expectancy of the Deterioration Path, for the specific mechanism;

ICn – the Influence Coefficient for the specific deterioration factor;

It is seen that LELC decreases as IC and LEDP increase, and vice-versa. The Influence coefficients were determined with the data collected in the review of failures in the field survey. It is clear that the LELC is strongly sensitive to the Influence Coefficient. This point stresses the sensitivity of the model to the relative effect of more than one deterioration mechanism acting simultaneously on the component.

3.6.4 Determination of the predicted service life (PSL)

The Predicted Service life in actual conditions is finally determined by multiplication of SLE by LELC for any deterioration mechanism detected in the first stage. Equation (3) describes the determination of PSL:

$$PSL = SLE * LELC_1 * LELC_2 * ...... * LELC_n \tag{3}$$

Where,
SLE – the Standard Life Expectancy
$LELC_n$ – the Life Expectancy Limiting Coefficient

The mathematical model is based on the factorial method and is sustained by the Performance Level which is determined using the CPFC.

4 Demonstrative example

The implementation of this method follows 5 steps:

- Step 1: Verification of the age of the building;
- Step 2: Identification of the types of deterioration mechanisms, using the appropriate Checklist of Failures;
- Step 3: Determination of the Component's Performance in Failure Conditions (CPFC) for each deterioration mechanism;
- Step 4: Determination of the Life Expectancy Limiting Coefficient ($LELC_n$) for any deterioration mechanism (defined in Step 2);
- Step 5: Calculation of the Predicted Service Life (PSL) using the LELC for each failure.

The method was tested on several cases of premature deterioration. The following example, which deals with natural stone cladding, was selected for the purpose of demonstration.

4.1 General data and deterioration mechanisms

The structure is a 7-story building with natural stone cladding. The degradation mechanisms found were:

- Deterioration of the stone caused by its poor quality (High absorption combined with low rigidity)
- Deterioration of the stone caused by the unprotected steel in a "corrosive" environment

Based upon this and using the photo-checklist-tables for the determination of the CPFC, it was found that the CPFC was 50% for the first, and 65% for the second, deterioration mechanism.

4.2 Determination of the PSL

The Predicted Service Life is now calculated by determining the Life Expectancy Limiting Coefficient for the deterioration mechanisms identified in Step 2. The LEDP for the deterioration mechanisms (found to be Nos. 12 and 10), and the LELC were calculated to be 0.65 and 0.85, with Influence Coefficients of 0.5 and 0.3 respectively.

The PSL, as derived from pertaining to these Coefficients was calculated using expression (3) and found to be 22.1.

5 Conclusion

The method presented in this paper was developed as a tool for the prediction of the service life of building components for maintenance purposes. The method is therefore based on an examination of the actual conditions affecting the component in question and a symptomatic analysis. This tool is practical and simple to use in the establishment of an effective maintenance policy.

The advantages of the method may be summarized as follows:

1. Uniformity of criteria for the performance level and for the detection of deterioration mechanisms. The method is sustained by systematic tables for the CPFC and the LEDP that form a consistent foundation for the estimate of the Service Life.
2. Symptomatic characterization of deterioration mechanisms. The methodology does not require detailed information or knowledge concerning the quality of workmanship, the quality of materials, or adverse environmental conditions.
3. User-friendliness. It is based on a simple 5-step procedure.

The disadvantages of the methodology are:

1. High sensitivity in the first year of the components – at age 2 years, a tolerance of 10% in the CPFC may result in an uncertainty of 50% in the evaluation of the Predicted Service Life.
2. The factors that impact the final output of the procedure are the Influence Coefficients, determined on the basis of a subjective evaluation by the developers of the methodology. These factors may be different in diverse climatic or atmospheric conditions.
3. The method requires a large investment in terms of time order to develop the database of deterioration patterns, IC_s, and the photo-table for the determination of deterioration mechanisms.

6 References

Architectural Institute of Japan (1993), *The English edition of Principal guide for service life planning of buildings*, Tokyo, Japan.

Feld, J., Carper, K. L. (1997). *CONSTRUCTION FAILURE, Second Edition, John Wiley & Sons, Inc. New York.*

Henriksen F., (1995) Reactions of Gases on Calcareous Stones under dry conditions in field and laboratory Studies. *Water Air and Soil Pollution* V85 Dec 1995, pp. 2707-2712.

Masters, Larry w., Brandt Erik, (1987), Prediction of Service life of building materials and components, CIB W80/RILEM 71-PSL- Final Report.

Hermans, M., (1995), Deterioration characteristics of building components- A data collecting model to support performance management, Eindhoven University of Technology, Holland. ISBN 90-386-0084-4

Searls C. L. & Thomasen S. E., (1991) Repair of the Terra-Cotta Facade of Atlanta City Hall. *Proceedings of the 2nd International Conference on Structural Repair and Maintenance of Historical Buildings* 1991, pp. 247-257.

Shohet, I.M., AND Laufer, A. (1996) Exterior cladding methods: A Techno-economical comparison". *Journal of Construction Engineering and Management*, American Society of Civil Engineering, 122(3), September 1996, pp. 242-247.

158 ASSESSMENT OF BUILDING REHABILITATION EXPEDIENCY IN BULGARIA

S.N. Tzonev and D.G. Nazarski

University of Architecture, Civil Engineering and Geodesy, Sofia,
Bulgaria

Abstract

The basic features of the methodology for technical and economic analysis and assessment of the rehabilitation expediency for existing industrial buildings and facilities are presented in the paper. This is a very current problem in Bulgaria. Industrial buildings and facilities built more than 15-20 years ago are not in good condition especially from the point of view of their reliability and durability. At present, because of the privatization running, decisions are being taken for rehabilitation or new construction. The methodology is based on the results from field and laboratory tests of the physical and mechanical properties of the structural materials (concrete, steel). On this basis the actual bearing capacity and reliability of the structures subject to continuous action of various aggressive environments as well as climatic and force impacts could be assessed. The condition of the structures is the ground for conducting a technical and economic analysis and assessment for the expediency of undertaking respective rehabilitation actions as to reach an adequate reliability and durability of the industrial buildings and facilities during their service life.

Keywords: depreciation period of buildings, building components durability , life cycle economics, building rehabilitation, building structures reliability, service life

1 State of the industrial building structures

The change of the physical and mechanical properties of the structural materials used in the reinforced concrete and steel structures of the buildings and facilities of fertilizer plants is at the root of their reliability and durability reduction in the course of time [Durability, 1987].

Durability of Building Materials and Components 8 (Volume Three). *Edited by M.A. Lacasse and D.J. Vanier*. Published in 1999 by NRC Research Press, Ottawa ON K1A 0R6, Canada. ISBN 0-660-17742-0

From the investigations conducted in the last 15-20 years on reinforced concrete and steel structures in the mineral fertilizer plants in the towns of Stara Zagora, Devnia, Dimitrovgrad and Vratza, it was estimated that the concrete and the reinforcement of the reinforced concrete structures corrode very intensively in aggressive environments like ammonium sulfate, ammonium nitrate, carbamide, etc. Some of the structures require major repair every 3-5 years. The reduced durability of the structures is mainly due to poor quality of corrosion protection at time of construction as well as to regular leakage from equipment over structural elements.

It was found during the investigations that in the plants for mineral fertilizers in Bulgaria the liquid, solid and gaseous environments by their chemical contents and concentration could be classified as "strongly aggressive" with respect to the reinforced concrete as a whole, and to the concrete and reinforcing steel separately.

As a result of the aggressive environments, the concrete strength reduced at an average of 5-8% annually, and the reinforcing steel corroded at a depth of 0.2-0.35 mm. After a period of 4 years, the concrete in some structural elements has lost 20-30% of its designed strength, and the reinforcing steel rods have corroded to an average depth of 1.0 mm. These changes are the root causes of the designed bearing capacity and deformability reduction of structural elements and structures as a whole. They are accompanied by damage and cracks in the concrete surface, breaking the concrete protective coating of the reinforcement and reducing the designed cross-section of the reinforcement.

2 Technical analysis of the rehabilitation necessity

A static/structural analysis is made of each structure followed by an assessment as to whether an individual structure is in "pre-emergency" or "emergency" condition. The diagnosis for the condition of a structure is the basis for developing a special structural design for its rehabilitation in order to reach the designed parameters with respect to bearing capacity and deformability.

Taking into consideration the repair and restoration works carried out in the last 15-20 years, the conclusion that can be drawn is that the investments for those repairs lay within 70-80% of the respective cost for a new construction [Kelly, 1990]. That is why, in a number of cases decision is made to erect new structures and facilities instead of repairing the existing ones.

The rehabilitation of industrial buildings and facilities is closely related to economic issues. The ultimate aim of this process is the raising of the reliability and durability of individual structural components and systems, thereby increasing the durability of the whole system.

The improvement of the physical and mechanical properties as well as the structural and operational reliability of the components of a system are connected to investment levels. In return, however, the operational and production costs are expected to be lower. It is of primary importance whether the total effect of a rehabilitation is higher than the one in a new construction (when accomplishing one aim), i. e. it is necessary to prove the expediency of carrying out rehabilitation steps against a new construction.

3 Research methodology

The principles and methods for assessment of investments in the building industry are used for economic analysis [CIB, 1991].

Let us imagine an industrial building or facility having a specified economic service life. According to the norms in Bulgaria [Regulations, 1994] it is expressed with the depreciation period which is related to buildings and facilities but not to their components.

During the depreciation period of a building or facility which will be generally called below a "system", changing or rehabilitation of some components is needed. We assume that the system consists of *m* such components and each of them needs expenses I_{iR} $(i = 1 \div m)$ that may be considered as investment. The service life of each component in case of a rehabilitation is determined through its depreciation period T_{iR}, and the annual operating costs are P_{iR}. It is accepted that the depreciation period for the whole system is T_s, the number of rehabilitation cases for the component *i* during the service life of the system being $n_{iR} = \frac{T_s}{T_{iR}} - 1$. The total expenditures for one component during the period T_{iR} are $I_{iR} + P_{iR}T_{iR}$ Let's discount those expenditures to the present (the year of the analysis) for all components subject to rehabilitation [CIB, 1991]. Given that the expenditures I_{iR} and $P_{iR}T_{iR}$ are made at the beginning of the period T_{iR}, the result is

$$LCC_{iR} = I_{oiR} + P_{oiR}T_{iR} + \frac{I_{iR}+P_{iR}T_{iR}}{(1+r)^{T_{iR}}} + \frac{I_{iR}+P_{iR}T_{iR}}{(1+r)^{2T_{iR}}} + ... + \frac{I_{iR}+P_{iR}T_{iR}}{(1+r)^{n_{iR}T_{iR}}} \qquad (1)$$

where:

LCC_{iR} = the discounted total expenditures for an unit measurement for the component *i* of the system;

I_{oiR} = investments for an unit measurement for the component *i* prior to the beginning of its rehabilitation;

P_{oiR} = annual operating costs for an unit measurement for the component *i* prior to the beginning of its rehabilitation;

I_{iR} = investment for an unit measurement of rehabilitation for the component *i*;

P_{iR} = annual operating costs for an unit measurement for the component *i* during its depreciation period;

n_{iR} = number of rehabilitation cases for the component *i* during the depreciation period of the system T_s;

r = rate of return on investment or annual interest rate.

Equation (1) can be written in the following way:

$$LCC_{iR} = I_{oiR} + P_{oiR}T_{iR} + (I_{iR} + P_{iR}T_{iR})\left[\frac{1}{(1+r)^{T_{iR}}} + \frac{1}{(1+r)^{2T_{iR}}} + ... + \frac{1}{(1+r)^{n_{iR}T_{iR}}}\right] \qquad (2)$$

The expression in the square brackets represents a geometric progression. Calculating the sum of its terms and using the relation $n_{iR} = \frac{T_s}{T_{iR}} - 1$, after making transformations we have

$$LCC_{iR} = I_{oiR} + P_{oiR}T_{iR} + (I_{iR} + P_{iR}T_{iR})\frac{1-(1+r)^{T_{iR}-T_s}}{(1+r)^{T_{iR}}-1} \tag{3}$$

Letting $A_i = \frac{1-(1+r)^{T_{iR}-T_s}}{(1+r)^{T_{iR}}-1}$ **(4)**

we have

$$LCC_{iR} = I_{oiR} + P_{oiR}T_{iR} + (I_{iR} + P_{iR}T_{iR})A_i \tag{5}$$

The expenditures for a system consisting of *m* components subject to rehabilitation are

$$LCC_{sR} = \sum_{i=1}^{m} \left[I_{oiR} + P_{oiR}T_{iR} + (I_{iR} + P_{iR}T_{iR})A_i \right] \tag{6}$$

The value of quantity A_i with variable quantities of T_{iR}, T_s and r is shown in Table 1. The value of T_s varies within the limits of 5 to 30 years, which corresponds to Bulgarian norms for depreciation , and the rate of return r is assumed in the range of 4 to 8% annually. This corresponds to the current and the prognosticated market situation under the conditions of the currency board system introduced in Bulgaria on July 1997.

It is seen from the data for the coefficient A_i in Table 1 that with the increasing of period T_{iR} at a fixed depreciation period of the system T_s, the value of A_i decreases and is equal to zero when $T_{iR} = T_s$.

When calculating LCC_{iR} according to Formula (5) it is important to know the relation between I_{iR}, P_{iR}, and T_{iR}. The relationship between I_{iR} and T_{iR}, i.e. the relationship between the investment for rehabilitation and the service life can be found from experience. Besides, the rehabilitation of a certain component can be realized at different levels (with more or less investments), representing usually part of the investment necessary for the component of a new system. It is reasonable to expect that carrying out a rehabilitation with bigger investments will lead to higher durability and lower operating costs. In the present analysis due to a lack of reliable data from the field for the relationship between I_{iR}, P_{iR}, and T_{iR} we suggest the following approach offering a possibility for comparison between a rehabilitation case and a new construction.

Fig. 1 shows curves indicating the change of the life cycle cost - LCC_{iR} for rehabilitation of the system component *i*.

The curves designated $I^1_{iR}, I^2_{iR}, I^3_{iR} \ldots I^k_{iR}$ show the variation of LCC_{iR} at different levels set for the investments for rehabilitation (from *i* to *k*). It is convenient that I_{ik} be assigned values that are part of the investments for the component *i* in a new construction - I_{iN} , for example, $I^1_{iR} = I_{iN}; I^2_{iR} = 0.9I_{iN}; I^3_{iR} = 0.8I_{iN}$ and so on. The service life of the component T_{iR} varies with investment level. The operating costs P_{iR} are assumed as known at a given level of rehabilitation. If the calculations are made using Equation (5), the rehabilitation options corresponding to different whole system depreciation

Table 1: Values of A_i with variable T_s, T_i and r

T_i	T_s (years)																	
	r = 4%						r = 6%						r = 8%					
(years)	5	10	15	20	25	30	5	10	15	20	25	30	5	10	15	20	25	30
1	3.62	7.43	10.56	13.13	15.24	16.98	3.46	6.80	9.29	11.16	12.55	13.59	3.31	6.25	8.24	9.60	10.53	11.16
2	1.36	3.30	4.89	6.20	7.28	8.17	1.30	3.01	4.30	5.26	5.97	6.51	1.24	2.76	3.80	4.50	4.99	5.31
3	0.60	1.92	3.01	3.90	4.63	5.23	0.60	1.75	2.63	3.29	3.78	4.15	0.55	1.60	2.32	2.81	3.14	3.37
4	0.23	1.23	2.06	2.74	3.30	3.76	0.21	1.12	1.80	2.31	2.69	2.97	0.20	1.02	1.58	1.96	2.22	2.40
5	-	0.82	1.50	2.05	2.61	2.88	-	0.75	1.30	1.72	2.03	2.27	-	0.68	1.14	1.46	1.67	1.82
6		0.55	1.12	1.59	1.98	2.80		0.50	0.98	1.33	1.60	1.80		0.45	0.85	1.12	1.31	1.43
7		0.35	0.85	1.26	1.60	1.88		0.32	0.74	1.05	1.29	1.46		0.29	0.64	0.88	1.05	1.16
8		0.20	0.65	1.02	1.32	1.57		0.18	0.56	0.85	1.06	1.21		0.17	0.49	0.71	0.86	0.96
9		0.09	0.50	0.83	1.10	1.32		0.08	0.43	0.69	0.88	1.02		0.07	0.37	0.57	0.71	0.80
10		-	0.37	0.68	0.93	1.13		-	0.32	0.56	0.74	0.87		-	0.28	0.46	0.59	0.68
12			0.18	0.45	0.66	0.84			0.16	0.37	0.52	0.64			0.14	0.30	0.42	0.49
14			0.05	0.29	0.48	0.64			0.04	0.23	0.37	0.48			0.04	0.19	0.29	0.36
16			-	0.17	0.34	0.48			-	0.13	0.26	0.36			-	0.11	0.21	0.27
18				0.07	0.23	0.36				0.06	0.18	0.27				0.05	0.14	0.20
20				-	0.15	0.27				-	0.11	0.20				-	0.09	0.15
30						-					-	-						

periods T_s , and the interest rate (r) can be analyzed. The expenditure curves LCC_{iR} at variable investments I_{iR} offer a possibility for fixing the least durability values of the component $I^2_{iR}, I^3_{iR}...I^k_{iR}$ for which the total expenses for rehabilitation LCC_{iR} are equal to those in a new construction - LCC_{iN} indicated with the straight line in Fig. 1. As expected, after a rehabilitation the durability of the component observed is lower than the one in a new construction T_{iN}.

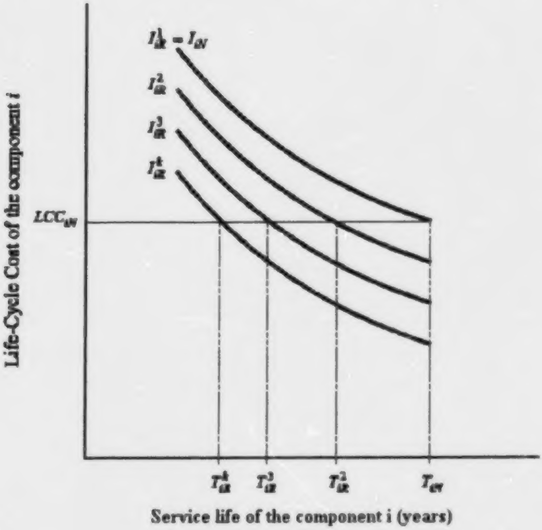


Fig. 1: Estimation of the least service life of the component *I* at different levels of rehabilitation

4 Results

Using the method illustrated in Fig. 1 the rehabilitation expediency can be determined for all components of the system. The data could be interpreted more clearly in the way shown in Fig. 2. It indicates the relation between the relative investments $\frac{I_{iR}}{I_{iN}}$ and the relative durability $\frac{T_{iR}}{T_{iN}}$. Cases of component durability in a new construction are observed (T_{iN} = 6 to 10 years) as well as those of a rehabilitation (T_{iR}=3 to 9 years). The analysis is conducted at a system depreciation period T_s = 15, 20 and 25 years and an interest rate r = 4%, 6% and 8%. These data are typical for the industrial buildings' sanitation in Bulgaria.

The data in Fig. 2 show that at a lower system period T_s the highest possible investments for a rehabilitation are less than those with a system of higher depreciation period (at a given durability of the component participating in a system of a new construction and a fixed level of the operating costs). The alteration of the interest rate r is almost without an influence on the relation "relative investment - relative service life".

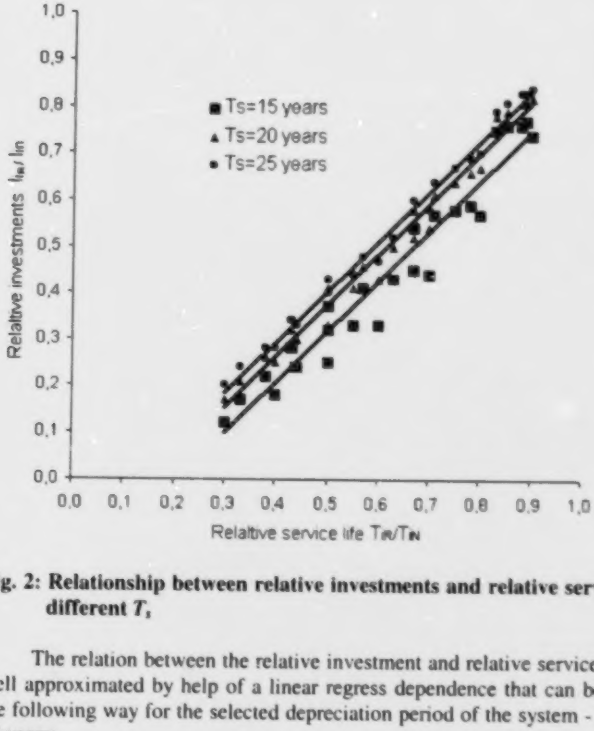


Fig. 2: Relationship between relative investments and relative service life for different T_s

The relation between the relative investment and relative service life can be well approximated by help of a linear regress dependence that can be written in the following way for the selected depreciation period of the system - 15, 20, and 25 years:

if T_s = 15 years $$\frac{I_{iR}}{I_{iN}} = 1.08\frac{T_{iR}}{T_{iN}} - 0.23 \qquad (7)$$

if T_s = 20 years $$\frac{I_{iR}}{I_{iN}} = 1.10\frac{T_{iR}}{T_{iN}} - 0.18 \qquad (8)$$

if T_s = 25 years $$\frac{I_{iR}}{I_{iN}} = 1.11\frac{T_{iR}}{T_{iN}} - 0.15 \qquad (9)$$

For approximate calculations, the following summarized regress dependency including the data for T_s can be used within the range of 15 to 25 years:

$$\frac{I_{iR}}{I_{iN}} = 1.10\frac{T_{iR}}{T_{iN}} - 0.19 \qquad (10)$$

The above equations can be used for calculating the highest value of the economically justified investment for rehabilitation of a system component. When substituting them in Equation (5) the total expenses for a reconstruction can be calculated, which, after comparing them to those in a new construction, will indicate the best economically justified solution.

After the economic justification of the rehabilitation expediency for each component, the rehabilitation of the whole system can be assessed with regard to economic justification. This can be done by comparing the total expenses for reconstruction calculated with Formula (6) to those in a new construction, the methodology for making the analysis being the same.

5 Conclusion

The methodology for technical and economic analysis described offers a possibility for accounting the durability and the financial parameters of individual structural components in a building. Using the information from the Bulgarian experience in industrial buildings, rehabilitation options or a new construction can be justified.

6 References

Durability of concrete in service, (1987) Committee 201, *American Concrete Journal*, Vol. 59, No. 2.

International Council for Building Research Studies and Documentation (CIB) (1991) *Economic Methods and Risk Analysis Techniques for Evaluating Building Investment - a Survey*. Publication 136, Rotterdam.

Kelly, S.Y., Marshal, P.C. (1990) *Service Life of Rehabilitated Buildings and Other Structures*, ASTM, Baltimore.

Regulations on Depreciation Norms (1994) Saloton publishing house, Sofia

159 A SERVICE LIFE DESIGN FOR LIFECARE MANAGEMENT

D.P. Wyatt[1] and A. Lucchini[2]

[1]University of Brighton, UK, [2]University of Milan, Italy

Abstract

No holistic life care methodology currently addresses life design, building maintenance or asset management service loss problems. But this is likely to change through the promotion and adoption of a service life practice as those securing and maintaining the life quality of building and building stocks understand the benefit from adopting service life planning and reliability engineering methodologies in design. Such changes may be accelerated due to the sustainable agenda pressures and the need to reduce building ownership costs arising from poor designed or building life quality. Nevertheless, designing and managing buildings on a life time basis requires a proper understanding of the design service life relationships among the various materials, elements and the building as a whole. It also requires a proper grasp of how service life may be used in life care as a management and life care planning tool. Further, service life may have a significant impact upon future life designed buildings and should be seen as the corner stone of asset management seeking more certain ownership costs. Asset and portfolio managers themselves need to also understand how they can make a significant contribution to sustainable practices for both their existing and new building and to promote a continuous product quality improvement. Finally, the time has come for design and life care management to address their service lives and to evolve a sustainable service life future.

Keywords Durability, service life, service life mapping, performance auditing, life care management, sustainable building.

Durability of Building Materials and Components 8 (Volume Three). *Edited by M.A. Lacasse and D.J. Vanier*. Published in 1999 by NRC Research Press, Ottawa ON K1A 0R6, Canada. ISBN 0-660-17742-0

1 Introduction

It is no longer a matter of passing interest but now necessity to identify a built environment that fits within the constraint of both being environmentally compatible and sustainable. In consequence, it is to those that own, use and manage buildings that society may now have to turn to in order secure those changes necessary to secure an effective life time management of buildings and their built environments.

Yet, in the very striving for this effective building life time management, (or life care), there is a need to also appreciate the dynamic nature of change in society and its needs to meet changing requirements. Such requirements that might even threaten a building itself as well as destroy beliefs of enduring or sustainable building stocks. That is unless one can manage buildings through securing a strong service life practice by adopting appropriate business practice responses to both innovation (Baden-Fuller et al 1996) and best practice (or improvement through benchmarking (Zaire 1996)) and the life audit function

This service life focus or prediction and its planning is not new, but BRE's work (Bourke and Davies 1997) must be seen as timely focus in promoting this area more widely. Especially now, as those maintaining, upgrading or changing the built environment are likely themselves to face a form of carbon tax penalties via higher energy costs, (as their Governments tackle global warming whilst at the same time promoting sustainable practice). Finally, landfill constraints and rising waste disposal charges made on the basis of 'the polluter must pay' may also encourage a service life view as sustainable building becomes increasingly a legal enactment.

Such changes should not now be in doubt. But to really change, it is believed that there is now the need to shake off the old image of building maintenance and instead, talk about service life, serviceability and life care management. So one may have to begin with a view design for life' and in doing so understand those material lives chosen have a service loss risk. For example Figure 1 below, indicates how one may contexturalise this approach which in turn, may be seen as part of a building's facility or functionality linking its service life with its service loss and dependency upon the life care management practised.

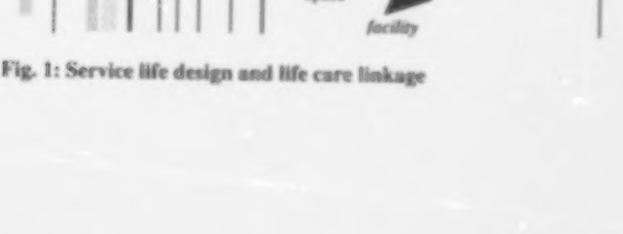


Fig. 1: Service life design and life care linkage

In fact, it is often those responses in life care that dictate the life and sustainable quality of what has been designed and built. So where an inadequate life care management strategy persists, not only will maintenance arrears or service losses grow, but their overall accumulative life on-costs (or cost of ownership) may be seen to become crippling to a business or non private enterprise like public sector housing, state schools or hospitals. Equally, if a building design is itself flawed, or the wrong life care choice has been made for economy and not on the basis of a full life cost, then there is every possibility that service losses will also grow with the likelihood of that building or its subsystems or facilities themselves may become unserviceable.

So design and life care management practices should be brought closer together so that they can both contribute to developing a whole life design vivendi (Luchini and Wyatt 1999) and to also improve building serviceability, the life quality of buildings and the facilities existing.

Finally, because of inevitable changes in organisation's life, the need to avoid a sense or loss of functionality has only a limited amount to do with life care and more to do with obsolescence. Nevertheless, as Figure 1 implies, the relationships between dismission and service life planning should come to form a common understanding for life care management.

2 Service life

Service life has been defined as that, "period of time after installation during which a building or its parts meet or exceed the performance requirements" (ISO 15686 1998). But such a building life is significantly dependant upon its external and internal environments as well the life care practised.

So how long should a building be sustained and by inference its constituent parts before it is itself replaced? Or does a building have a life whilst its constituent parts may 'come and go' within shorter periods of time or service life?

In fact it is doubtful today if there is such 'a thing' as a rational building life or many exemplars, of sustainable life buildings. We do have however, a growing understanding of durability and service life conditions, but we now need to take stock and ask where are we going with service life practice?

From the past, with its limited range of materials, a building would continue to be used until it fell down, or was rebuilt, or simply patched, mended, or altered etc. Here one may observe, those buildings altered or unaltered that have survived and their materials durability. But today, buildings are now more complex and diverse in size, form and function and use a wider range of materials with obvious differing durabilties (service lives) and life costs!

So, where a building life period is used, it has tended to be largely based on loan repayment, for example in the public sector, or a notional 10-20 or even 25 year period for commercial schemes with or without a 'collateral warranty' or finally a notional 30-35 year period for PFI Projects and Housing Association insurance.

What of tomorrow? Possibly managing carbon dioxide deficits, resource depletion and waste management, may be on the asset and design life agenda as they share a common link with the service life! This link may well be the way to move the past and the present into a common future of building life design, life care and asset management.

3 Service life mapping states

By building life, one means (in this paper) "that period which initially one may call the first life used in any project undertaking" (i.e. the commissioned design life laid down from the client brief or agreed or designed project life. So if at a future data the building is modified, there would be a need to re calibrated the original building life! This may lead to a clumsy methodology, but to really reflect the nature of such building change, it is believed that there are three broad periods of time or states in all building's life irrespective of how often they are altered or changed as intimated in Table 1.

Table 1: A proposed building life span break down matrix grouping

Permanent Life Span Elements	Semi -Permanent Life Span Systems	Short Lived Life Span Interiors
Roof Structure	Static Mechanical Service	Fit outs
Wall Element	Static Electrical Services	Floor Coverings
Floor Element	Plant and Equipment Boilers Lifts	Wall Coverings>
		Ceiling Systems
Stair Element	Treads	
Service Core	Partitioning Systems ><	
Plant Room	Window Systems	Seals Mastics
Basement Structure	High Class Joinery	Paint Systems
Foundation System	Door -Systems	Coatings
Sewer and Drainage – systems external works		

Here firstly, there is the long life status or life period. On reflection long life elements, like a building frame may have a potential life that could well extend centuries into a future and be part of that sustainable city's built environment that should have been developed by then. For example, a steel frame, despite being seen as a high embodied energy material may because of its inherent durability, evolving jointing and protection systems, can be so designed so that it can be used in more than one building, or on more than one site. In that sense, one might prior to the dismission stage, see this long life period as being a permanent life and in consequence be used to form a core or foundation to both building sustainability and building a service life practices.

Secondly, a building's construction may be made up of many components often of lesser life durations than long life, but still seen as having a medium life span. Such examples may include low pressure water systems, envelope and window or rain water systems. In that sense, one might see their status as being of a semi-permanent nature or of life span of a lesser life than the permanent part described above but still nevertheless significant!

Of course, either because of both the nature of tenancy or organisational changes or fashion responses or obsolescence as well as durability and service life reasons one might find short lived materials, components or systems used remaining in most buildings. Typical examples may range from building fit outs, surface, protective or jointing systems, through to problems affecting surface life cleanliness.

Nevertheless, building life at this point in time is not able to demonstrate a precise approach to life engineering like that found in the fields of electronics and the aero space industries. But, that is only a question of time.

Mean while one may come to see that a building has, or will have a range or mix of lives or service lives! So appropriate approaches need to be adopted for designing for life. Firstly, for example, one might consider identifying and addressing the long life parts of a building (LL) with an engineering approach i.e. limit states. Secondly, where there is a mix of components or materials, particularly those with a shorter to medium life times (ML) a factorial approach might be taken.

Better still, in terms of a population of manufacturers components, one might consider, especially in terms of sustainable practices, adopting a stochastic (or some other survivorship methodology) as well as using a reference service life. Having said that one needs to also recognise the convenience at this point in time of the factorial approach.

4 Life design

Whether viewing building permanency as a life focused way or approach to service life thinking, remains to be seen. But even a broad based building morphology and breakdown analysis of its material mixes of permanencies could help service life planning. It could also be used to evaluate many existing buildings and building stock based upon the recognition of a given building's typology's sub-systems, element or configurations. Such approaches would also facilitate life care and improved design management practices.

Table 2: Reference service life matrix states

Permanent Life State			**Seem-Permanent Life State**			**Short Lived Life State**			**Comments**
LL	LL	LL	ML	LL	LL	SL	LL	LL	LL may be assigned a matrix ratio value of 1
LL	LL	ML	ML	LL	ML	SL	LL	ML	
LL	LL	SL	ML	LL	SL	SL	LL	SL	The greater the variance from LL to SL or SL to LL the more important is the whole life cost analysis
LL	ML	LL	ML	ML	LL	SL	ML	LL	
LL	ML	ML	ML	ML	ML	SL	ML	ML	
LL	ML	SL	ML	ML	SL	SL	ML	SL	
LL	SL	LL	ML	SL	LL	SL	SL	LL	
LL	SL	ML	ML	SL	ML	SL	SL	ML	
LL	SL	SL	ML	SL	SL	SL	SL	SL	ML & SL will be some decimal part of LL

Returning to Table 1 (with the three states identified), one may now refine it further by bringing both service life and durability to a common reference point. So let the building's permanent state represent a long life (LL), its semi-permanent state or life (ML) and their short lived remains (SL). In consequence one can develop a life based reference matrix as shown in Table 2 above to a level of detail appropriate.

What one is suggesting then, is that, if any constituent part of a building or its sub-system has a lesser permanent life status than the part it forms e.g. as a value or ratio shown of 1, then that part could result in either costly or unplanned or unexpected maintenance problems. (It is proposed to explore the implications of this further for service life practice in a future paper).

In service life planning, one would then seek to both optimise cost and mix of service life strategies. to. So where a SL or ML state exists beyond an LL state, or SL state occurs before an LL, or ML state, clearly the life cost implications etc. must be appraised and any adverse impact in prioritization of maintenance addressed (Johnson 1999). There is also that opportunity to extend the 'first life' through adopting an upgrading or restructuring strategies set within a service life context and its associated embodied energy and CO2 tied up in existing building lives and new service lives.

5 Service life design planning

Gradually one may move both life design and life care management forward. Indeed, to life engineer using those properties of the materials irrespective of what form they appear in more fully. Whilst at the same time ensuring the right service life ratio is had. In short this approach characterises new possibilities (Pardee 1996) and whole life cost development will no doubt be a normal sustainable expectation.

Clearly there is a need to have a clear grasp of both the design process and life care and those problems in preparing a service life scope or life plan. Also it is not just the problem at the moment of not having all the manufacturer's service life data to hand, but also understanding (as our research has shown) the significant service loss variation one may find for the same component used in the same building!

Ideally, the value of each building element, system or their material would match the 'building life' or cycle periods of that building within a defined serviceability and replacement life cycle.

Likewise, the established full life cost of both the operational and dismission ownership would have to be determined to. One must likewise be mentally alert to issues relating to detailing, sequencing and quality control that can frustrate a service life intent and come to understand how such building analysis of these break downs may have varying permanency and service life needs. It is here that asset managers have a specific contribution to make drawn from their life care practices.

Other service life practice issues might also be addressed through the use of appropriate tally sheet, checklist, or 'aide de memoir', for example, Table 3 might help in a design review or evaluation or validation of an existing external roof or wall envelope design prior to replacement. Likewise a performance audit or environmental life evaluation might be carried out, say for a building facade, where the life design quality, the site location and its surrounding and climatic cycles faced may face varying intensity of prevailing wind and eddies, driving rain, air quality and diurnal cycles. Here differing service losses for the same component on differing elevations etc. may result!

Table 3: Aide de memoir characterisation audit

Location Matrix	**Environmental Audit**			**Serviceability Audit**
System/Element	Macro Level	Micro Level	Meso Level	
Component Materials				Risk of failure **Loss implications**
Component Materials				Risk of failure **Loss implications**
Component Materials				Risk of failure **Loss implications**

Whilst a significant basis of reliability engineering and measurement can be drawn upon, the serviceability design and audit quality needs to be critically broken down into manageable stages so that the respective systems or element are understood in their life in context. In fact, the service loss appraisal could be developed through an Ishikawa Fault tree analysis, appraising those critical aspects of a service life, or service life profile and balancing any significant service loss threat with remediation or service repair options or replacement times within a life costing.

6 The building life development

One must now begin to draw this paper to a close but also indicate the relationship for both service life practice and the building. In doing so it should become clear that the service life forms an important building block and contributor to a buildings life care and future sustainable and life care management.

So turning to Figure 2 (over) 'a building's service life and serviceability framework' there is a need to think in terms of an initial target service life. This target service life begins with a broad outline mapping the design concepts LL and ML areas. As more detail comes to hand during the development of the design becomes increasingly refined and gradually giving away to balanced life ratios viz. a viz. Tables 1 and 2. So an accepted service life profile can be developed and by the same token also audited or used to manage or plan for life care needs.

In following Fig. 2, it should be clear differing mixes of systems, products and materials brought together in a changing environment will inevitably result in differing rates of service loss. So in a life care sense, one must develop the project's or building's service life profile to assist those managing buildings after hand over. Nevertheless, the possibilities of service life whether in design or management are seen as a positive way forward for asset management and sustainable development.

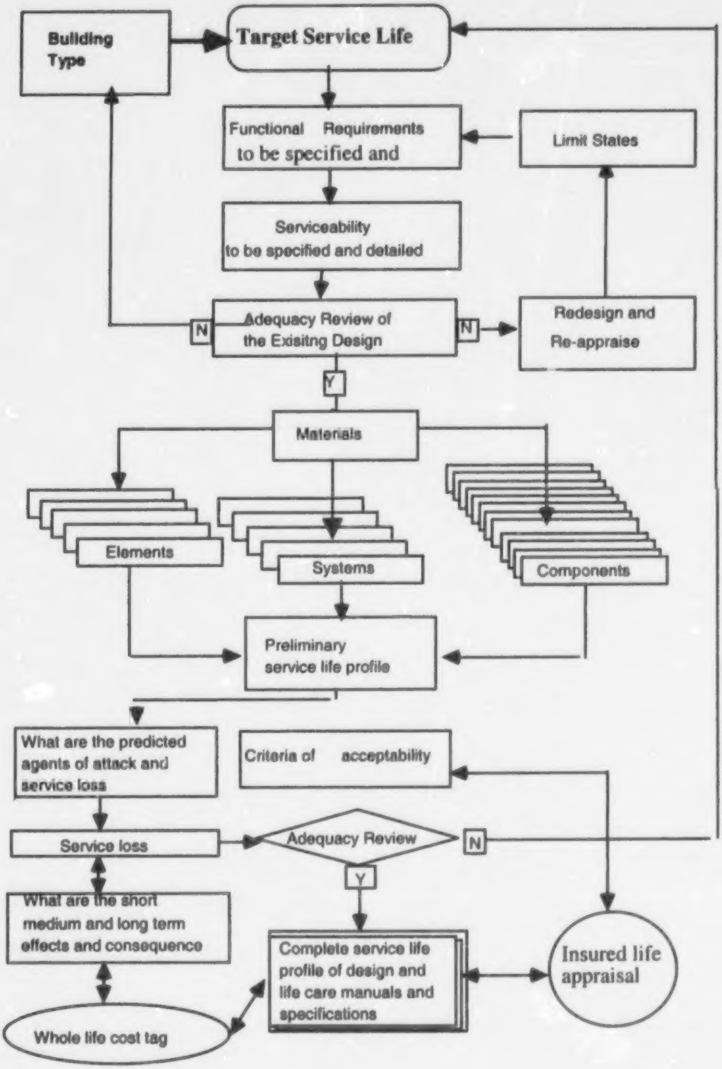

Building Type
Target Service Life
Functional Requirements to be specified and
Limit States
Serviceability to be specified and detailed
Adequacy Review of the Exisitng Design
N
N
Redesign and Re-appraise
Y
Materials
Elements
Systems
Components
Preliminary service life profile
What are the predicted agents of attack and service loss
Criteria of acceptability
Service loss
Adequacy Review
N
Y
What are the short medium and long term effects and consequence
Complete service life profile of design and life care manuals and specifications
Insured life appraisal
Whole life cost tag

Fig. 2: Service Life and serviceability briefing framework

Likewise life care needs and associated costs of ownership or environmental degradation will inevitably vary. So one needs to decide how much attention to life designing one should or can afford.

Finally, one could suggest the use of survivorship rates for given components, assemblies and controls will increasingly bring precision to securing the corner stone of service life practices. This will come to be seen as important once product improvement is encouraged and service lives form part of life performance and performance auditing.

7 Life care

Adopting service life planning and service life as practice would improve and enable an audit framework to draw on asset and portfolio management experiences. Such experiences should however also be seen in the context of service life planning. Life care in fact begins before the design appears on the drawing board or in the CAD laptop and ends after the last of the original supply chain's waste stream is removed from the site (Wyatt and Soronis 1998).

Table 4: Life care audit scope

Activity	Stage	Notes
Life management	Procure new or replace, repair or service	Neglect profile risk assessment Cost breakdown analysis
Life care practice	Servicing intervals and check lists	Preventive action Curative action
Life and process safety	Life safety evaluation	Access repair replace ease etc.
Service life audit	Life care review Risk assessment for service loss Elemental Component matrix analysis Jointing or joining system Protective system Material-and systems durability of the building services Controls	Life care action plan
Commissioning-decommissioning	Review of life care requirements and management action plan	Life care manuals Service life handbook Check lists
Servicing	Routine and dedicated	Cleaning, surface upgrades

Like the earlier tables and figures, there is an implied hierarchical nature in service life planning and its dependencies The importance, however, of this section is simply that if one wants to engineer life costed building, one needs to move the life care world into contributing, for example identifying those areas for improving reliability. In turn, one would begin to help develop the quality of reference service life data and encourage manufacturers as well as designers and those concerned in life care, to work together, to form improved product life quality management.

Simply, life care management, has an important part to play is securing service life practice and should encourage a continuous building life improvement cycle. One that would lead to both reliable and cost effective operational, a whole life crafted building and form a sustainable life building where durability and service life eco point relationship form part of the whole life assessment.

8 Conclusion

It has become clear, that designing for durability has an immensely important contribution to make to both the work of CIB W94 and CIB W80 as well as ISO task groups responsible for developing the Design Life of Building Standard.

Whilst there is a complex but important relationship between the building performance the designer may have pre-defined and the level of reliability achieved one cannot guarantee a building's future life. Nevertheless one can be prudent and accept the place of a service life in asset management and improve life care.

Concluding, it is now believed, that service life and its practice will come to form and be seen as the corner stone of building asset management's life care. So adopting the service life approach that reflects materials, components and systems service loss and durability would help to improve cost certainty of building ownership and begin to address the challenges posed in striving for sustainable cities and buildings.

9 References

Baden-Fuller & Pitt M (1996) Strategic Innovation Routledge 22-26

Bourke K and Davies H (1997) Factors Affecting Service Life Predictions of Buildings. Building Research Laboratory Report BRE UK 26pp

ISO 15686 1998 Buildings Service life planning Part 1 General Principles BSI UK 10

Johnson M and DP Wyatt (1999) Preparation and prioritization of maintenance programmes 8dbmc Vancouver 10pp

Luchini A and Wyatt DP (1999) A Systematic Vivendi For Design For Durability 8dbmc Vancouver 10pp

Pardee WJ (1996) To satisfy and delight your customer Dorset Publishing House NY 190

Wyatt DP and Soronis G (1998) Life cycle assessment and the design agenda CIB W96. International Journal of Architectural Management Practice and Research 40

Zaire M (1996) Bench marking for best practice Butterworh Heinemann 112

PART TWELVE

LIFE CYCLE COSTING AND ECONOMICS

160 MODELING RUNNING AND MAINTENANCE COSTS FOR LIFE CYCLE COSTING APPLICATIONS IN BUILDINGS

A. Al-Hajj

The Robert Gordon University, Aberdeen, UK

Abstract

Life cycle costing is the technique of considering the initial and subsequent running costs and residual costs of an asset over the life of a project. Running costs are defined as the total cost of operations and maintenance costs of a building. The technique is accepted to be of theoretical merit but its practical development is hindered by two extreme factors i) the absence of data in the right form and ii) difficulties in handling the plethora of data when exists.

This paper describes the use of a novel approach, known as the cost-significance, for the development of simple models for running and maintenance costs in buildings. The models focus design and management effort on the high cost items. The results are drawn from analysis of operation and maintenance costs for university buildings over a period of 18 years demonstrating the feasibility of deriving a small number of items, 16% of the total number of items occurring in running costs and 30% in maintenance costs, which consistently represent some 87% of the total running costs of buildings and 70% of the total maintenance costs. The model can calculate the costs to an average accuracy of ±5% and ±13% for total running and maintenance costs respectively. The models were tested on new information and proved to be effective and consistent.

The paper also discusses the major applications of the developed methodology and models particularly considering data collection, recording and analysis for use in life cycle costing applications in buildings.

Keywords: building economics, cost modelling, Life-cycle costs, maintenance costs, operation costs, running costs, facilities management.

Durability of Building Materials and Components 8 (Volume Three). *Edited by M.A. Lacasse and D.J. Vanier*. Published in 1999 by NRC Research Press, Ottawa ON K1A 0R6, Canada. ISBN 0-660-17742-0

1 Introduction

Life cycle costing is the process of economic analysis to asses the overall cost of an asset including the cost of acquisition and the subsequent costs of operation, maintenance and disposal. When attempts have been made to apply life-cycle costing concepts in the building industry, owners, and managers have been thwarted by the lack of both well-accepted methodology of documentation of information and sound data from which to arrive at appropriate decisions.

Investment decisions in the construction and property industries continued to be made mainly on the basis of minimal capital costs being the driving factor to many promoters. There is, therefore, no lack of information on construction processes and costs during the initial stage compared to the little information available, on operation and maintenance costs of buildings. This may be blamed on the lack proper monitoring techniques and the feedback of information on the performance of materials and systems in a building over its life cycle. Even those with the will to embark on total life cycle costing were thwarted by the lack of useable information either about the real costs of operating and maintaining buildings or about the lives of different components fulfilling the same function (Spedding 1987, Mcdermott et al 1987). As a result, the output from total life cycle cost models is notoriously unreliable. (Ashworth 1993, Grover & Grover 1987).

This paper focuses attention on buildings' running costs which is an integral part of the overall life cycle costing study of any building project. The paper describes, using a new approach, the development of a model for running costs and another more specific model for maintenance costs in buildings from different categories. These models which would by their very simplicity facilitate and encourage data collection and analysis for Life Cycle Costing in buildings and might serve to improve our understanding of how to identify those costs which contribute most to the overall cost of buildings.

2 Definitions

BS3843 (1992) defined the life cycle costs as:

' the costs associated with acquiring, using, caring for and disposing of physical assets, including feasibility studies, research, development, design, production, maintenance, replacement and disposal; as well as all the support, training and operations costs generated by the acquisition, use, maintenance and replacement of permanent physical assets.'

The life cycle cost (LCC) of a building is defined as all costs that emerge throughout its entire life cycle- from construction, through operating and maintenance, to disposal. The maintenance costs are defined as the cost of keeping the building in good repair and working condition. They include painting, decorating and repairs. Operating costs are defined as the costs associated with operating the building itself (RICS 1983). They include the cost of cleaning, rates, energy and security. Running costs are defined as the sum of maintenance and operating costs.

3 Data collection and preparation

Data used for model development was obtained from York University. A minimum of 18 years' records dating from 1971 was available for 20 buildings made from residential, teaching and laboratory buildings. 15 further buildings from the Estate Management Office at Birmingham University, were used to test the accuracy of the developed models. In preparation of data there were four problems to resolve:

1. Data collected was converted to a standard structure and coding based on the Building Maintenance Information (BMI) framework (1988).
2. All costs were expressed in terms of £ per 100 m^2.
3. The data was discounted, to take account of inflation, to the year 1988 using the indices published by the BMI.
4. Different periodicities of the data were taken into account by aggregating it into a series of moving averages ranging in duration from 1 to 10 years. (Al-Hajj, 1991 PhD)

4 Methodology for models development

The methodology adopted involves checking the feasibility of applying Pareto's 80/20 rule to identify a small number of cost elements which represent a consistent and high proportion of the total running costs and total maintenance costs. The procedure is as follows. (Al-Hajj & Horner, 1998)

- Collect and record data in a readable and useful form.
- Plot in descending order of magnitude a graph of cumulative percentage cost versus cumulative percentage number of items.
- Determine the point beyond which each percentage increase in number causes a smaller percentage increase in cost. This is the point of maximum efficiency.
- Identify all the items whose cost is greater than or equal to the mean. The mean is the total of annual cost divided by the number of occurring items, the so-called cost-significant items, for each building.
- Determine the cost-significant items recurring most frequently.
- Development of models by progressively adding those cost-significant items progressively recurring less frequently until their total cost represents a sufficiently consistent proportion of the total running and maintenance costs.
- Test the models on new data, that is, data not used in their development.

4.1 The principles of cost-significance

Figure 1 shows the relationship between cumulative cost and cumulative number of items for the general category of buildings under consideration. The data is derived from the average annual cost for all cost items incurred annually. The curves clearly illustrate that: i) for running costs, 10% to 20% of the items contribute to 80 % to 90 % of the costs; ii) for maintenance costs, 30% to 40% of the items contribute to 80% to 90% of the maintenance costs. Both curves give a clear indication that a high proportion of costs is focused in a small number items with significant costs. These cost significant items were then identified (Al-Hajj, 1991) to be those items whose costs were greater than the mean incurring over the years and showing noticeable consistencies. These consistencies of the data allowed the research to contemplate the development of models which can represent the total running and maintenance costs sufficiently accurate for all practical purposes, yet which contains only the cost-significant items.

Table 1 illustrates the consistency of the relationship between V_s /V and N_s/N for both types of costs:

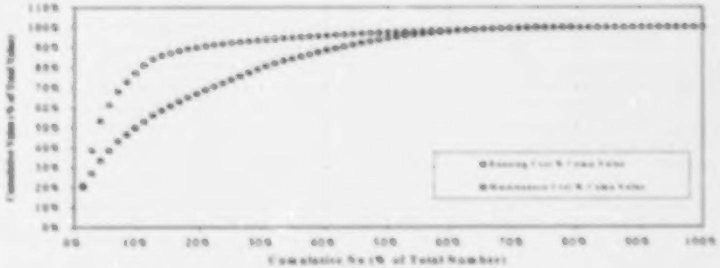


Fig. 1: Cummulative value vs cummulative number of running and maintenance costs for the general building category

Where V is the total cost

V_s is the total cost of items whose cost is greater than the mean

N is the total number of items

N_s is the number of items whose cost is greater than the mean

Table 1: Average value and average number of annual running and maintenance cost-significant items for all buildings

Building	Total Cost (V) £/100m²	Total Number (N)	Mean V/N	Vs/V %	Ns/N %
Running Costs					
Average	3601	63	56.8	88	19
Standard Deviation	585.82	3.84	8.32	1.93	2.48
Coefficient of Variation	16.71	16.36	16.5	2.19	13.28
Maintenance Costs					
Average	559.44	51	10.89	78	27
Standard Deviation	243.39	2.93	4.66	3	3
Coefficient of Variation	43.5	5.7	42.8	3.8	11.1

The models are will be developed based on the following concept:

$$T_c = \frac{1}{CMF} \sum_{i=1}^{n} CSI_i$$

Where,

T_c = total cost

CMF = cost model factor (ratio of the cost of the cost-significant items to the total cost)

CSI = cost of the ith cost-significant item (any item whose cost exceeds the mean).

4.2 Selection of CSI's for inclusion in the models

Items that consistently recurred in every year were automatically selected for inclusion in the model. As more cost-significant items that intermittently occurred are added to the model, its consistency, and its accuracy increased as expected. However, so does its complexity. We therefore progressively added to the core items those additional items which recurred progressively less frequently. In this way, a number of alternative models were developed for both the running and maintenance costs, each containing a different number of items and each with a different cost model factor. This is illustrated in (Al-Hajj & Horner, 1998 & Al-hajj 1991). As expected, in general, the accuracy of the model expressed in terms of the coefficient of variation of the CMF improves as the number of items increases. The models with CMF having the smallest coefficient of variation (C_v), were selected for further testing. These models are as expressed in Table 2:

Table 2: Cost models

Running Costs Model	Maintenance Costs Model
$R_c =$ [illegible] $\sum$ [illegible] $+e_1+e_2)+(a_1+a_2)+(o_1+o_2)+(m_1+m_2)$	$M_c = (1.37)\times\sum_{i=1}^{t}(d+f+s)_i$
where R_c = Total running cost cmf = Cost model factor (cmf=0.87) t = Time in years c_1 = Internal cleaning c_2 = Laundry e_1 = Gas expenditure e_2 = Electricity expenditure e_3 = Fuel oil expenditure a_1 = Management fees a_2 = Porterage (security) o_1 = Rates o_2 = Insurance m_1 = Internal decoration m_2 = Roof repair	M_c = Total maintenance cost cmf = Cost model factor (cmf=0.73) t = Time in years d = Decoration - external - internal (programmed) f = Fabric maintenance - windows external - glazing external - roof structure repairs - floor finishes s = Services maintenance - cold water service - sanitary fittings - boiler/calorifier rooms - LPHW services - air conditioning and ventilation - lifts and elevators - lighting - lamp replacement - refrigeration equipment - floor finishes - loose appliances - built-in fittings
Items in module contribute to about 16 % of total running cost items.	Items in module contribute to about 30 % of total maintenance cost items.

5 Accuracy of the models

The accuracy of the running and maintenance costs calculated using the models is the percentage difference between the cost predicted by the model and the actual costs.

The accuracy was tested in two ways: first, the models were tested on the information used in their development. This accuracy was called '*the expected accuracy*'. Both models were used to calculate the total costs over 18 years and for a series of moving averages with periodicity ranging from 2 to 10 years. Figures 2 and 4 show the results of this exercise for running and maintenance models respectively. The figures also show that the expected accuracy applied using the moving average technique clearly improves considerably as the periodicity increases. Running cost model accuracy ranges between ±5% at annual level to ±7% at 10 years moving average level. For maintenance costs, accuracy is shown to be less consistent due to the nature of maintenance items occurrence. The expected accuracy of the maintenance model, as shown in figure 4, fluctuated between ±30% at the annual level and ±13% with 10 years moving average period.

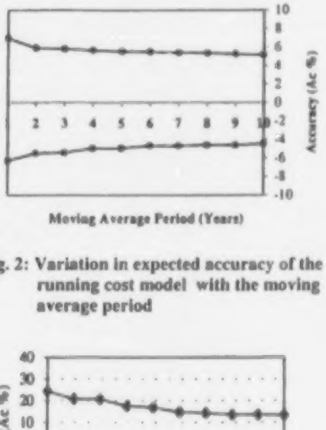


Fig. 2: Variation in expected accuracy of the running cost model with the moving average period

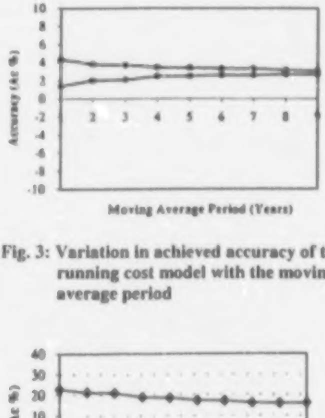


Fig. 3: Variation in achieved accuracy of the running cost model with the moving average period

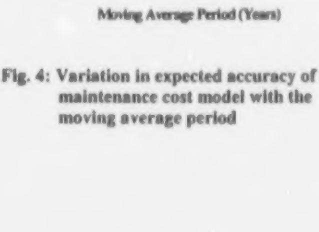


Fig. 4: Variation in expected accuracy of the maintenance cost model with the moving average period

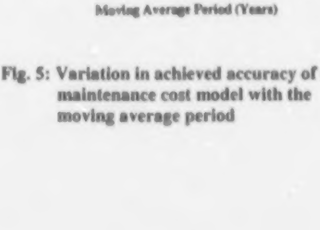


Fig. 5: Variation in achieved accuracy of the maintenance cost model with the moving average period

The models were then tested by using data from new buildings not been used in their development. Data from 12 additional buildings for the running costs model and further data of 15 buildings were used to test the maintenance costs model. Figures 3 & 5 show that the achieved accuracy, from both cost models, was within the expected range.

6 Applications

The changing nature of the maintenance and operation in buildings has been one of the main causes for the lack of uniformity in the method of collecting and recording data and lack of feedback of information on the performance of materials, building components and buildings. This in turns makes the analysis into life cycle costing unreliable which brings about the demand for a review of the methodology for collecting, modelling and analysing data, on maintaining and operating buildings, for life cycle costing analysis purpose.

The models developed provide a focus of attention on the main cost items over the operating life cycle of buildings. This in turn provides simpler tool for conducting occupancy cost analysis and reducing costs associated with data gathering. This simplistic approach allows a user-friendly mechanism for incorporating information on main cost areas of facilities management, and directs the designer to cost significant parts of the building. The described methodology provides decision makers with a simple tool to evaluate and assess buildings using the concept of life cycle costing as an effective and useful tool to aid the decision-making process.

7 Conclusions

The paper described and presented the methodology for developing simple cost models for running and maintenance costs in buildings. The models are shown to be easy to use, simple in structure, and simple in concept and capable of achieving reasonably accurate representation of the real data used in their development.

The paper also shows that the methodology can provide a simplistic analysis of alternatives based only on the most significant items of cost since only a small number of items are involved in the models without loss in the accuracy of predictions. The remarkable consistency of cost-significant elements across a range of building types allowed the development of simple models of operating and maintenance costs.

Because the models contain only a small number of items they can considerably simplify the process of monitoring, collecting and feedback of data for quick but sufficiently accurate performance evaluation in buildings.

8 References

Al-Hajj, A. (1991), "Simple Cost-Significant Models for Total Life-Cycle Costing in Buildings", PhD Thesis, The University of Dundee, U.K.

Al-Hajj, A. & Horner, R.W.H. (1998), "Modelling the Running Costs of Buildings", *Construction Management and Economics*, 16, E & F.N. Spon, London, 459-470.

Ashworth, A. (1993), "How Life-Cycle Costing could have Improved Existing Costing". In Life-Cycle Costing for Construction, edited by Bull, J. Black Academic and Professional. Chapman & Hall, London.

Building Maintenance Information Ltd (BMI), (Jan 1988) "Standard Form of Property Occupancy Cost Analysis: principles, instructions, definitions and elements", RICS. Connelly-Manton (Printing) Limited, London.

BMCIS, (Feb. 1984) "Standard Form of Property Occupancy Cost Analysis: principles, instructions, definitions and elements", *Building Maintenance Cost Information Service*. RICS. Connelly-Manton (Printing) Limited, London.

British Standard Institution, BS3811 (1984), "British Standard Glossary of Maintenance Management Terms in Terotechnology", London.

Bull, J.W. (1993), "Life-Cycle Costing for Construction", Academic and Professional. Chapman & Hall, London.

Dale, S.J. (1993), "Introduction to Life Cycle Costing". In Life-Cycle Costing for Construction, edited by Bull, J. Black Academic and Professional. Chapman & Hall, London.

Flanagan, R. & Norman, G., (1983), "Life-Cycle Costing for Construction", RICS, Surveyors Publications Ltd, London.

Flanagan, R. & Norman (1987), "Life-Cycle Costing: Theory and Practice". RICS, Surveyors Publications Ltd, London.

Kooren, J.A. (1987), "The Balancing of Building Costs-in-Use against Investment", CIB Proceedings of the fourth International Symposium on Building Economics, in Pedersen, D.O. & Soderberg, J. (Eds.), "Building Economics", Session A, Danish Building Research Institute, Copenhagen, pp148-158.

McGeorge, J.F. (1993), "The Quality to Design and Life Cycle Costing in the Health Service". In Life-Cycle Costing for Construction, edited by Bull, J. Black Academic and Professional. Chapman & Hall, London.

Pullen, L. (1987), "The Economic Significance of Building Maintenance". In Spedding, A. (Ed.), *Building Maintenance Economics and Management*, E & F.N. Spon, London, pp373-382.

Saket, M.M., McKay, K.J. & Horner, R.M.W. (1986), "Some Applications of the Principle of Cost-Significance". *International Journal of Construction Management and Technology*, Vol 1, No 3, pp5-22.

Spedding, A. (1987), "Management of Maintenance- the Need for and Uses of Data". In Spedding, A. (Ed.), *Building Maintenance Economics and Management*, E & F.N. Spon, London, pp37-47.

161 FORECASTING REHABILITATION EXPENDITURES: THE SHQ SOLUTION

R. Chamberland

Société d'habitation du Québec (SHQ), Gouvernement du Québec, QC, Canada

Abstract

Faced with aging public housing stock comprising 65,000 low-rental housing units, in 1995 the Société d'habitation du Québec (SHQ) initiated a building components rehabilitation program (CRP). An examination of housing data enabled the SHQ to establish a profile for its public housing stock according to various general criteria including building age, floor space, number of housing units, dwelling category, region and client type. Subsequently, the SHQ did a more detailed characterization of the buildings from a budget standpoint and involving the most important components such as outside walls, windows, roofing, balconies, kitchen, bathroom and flooring. After determining the service life and replacement cost of the components in question, the SHQ established rehabilitation timetables as well as cost forecasts for a period of 40 years (1985 to 2025). In addition to producing data sheets specifying the criteria and the preferred rehabilitation methods, the SHQ wishes to make available to its agents, municipal housing authorities, COOPs and non-profit organizations housing management tools that can be adapted to their particular needs. It is currently developing a computer software application incorporating budget forecasting methods established under the CRP. Designed to be user-friendly, this tool must enable managers to "personalize" the settings according to the characteristics of their housing units and produce reports in table and graphic form. This information processing tool could be very useful for any group involved in planning and cost forecasting as these relate to property rehabilitation and repair.

Key words: building characterization, service life of component, rehabilitation cost, budget forecast, housing management, processing tool, computerization.

Durability of Building Materials and Components 8 (Volume Three). *Edited by M.A. Lacasse and D.J. Vanier*. Published in 1999 by NRC Research Press, Ottawa ON K1A 0R6, Canada. ISBN 0-660-17742-0

1 Purpose of the presentation

This presentation gives a summary of the SHQ's initiatives within the framework of its building components rehabilitation program (CRP) : the objectives, the characterization of public housing stock according to building age, timetables for future work, and budget forecasts. It also describes a management tool : a computer program designed to assist housing managers perform cost forecasting.

1.1 The SHQ's aging public housing stock

Quebec built it's first public housing units in the early 1970's. Today more than half the buildings making up the public housing stock are over 20 years old (Figure 1). This observation naturally leads us to predict a substantial increase in the amount of rehabilitation work that will be required for building components and a related escalation in rehabilitation costs.

1.2 Planning to help cut costs

The care taken to quantify this situation and plan its evolution will enable a reduction in unforeseen circumstances, allow effective measures to be developed and most certainly help cut costs (component defects, damage-related costs, work backlog and loss of control of the situation).

1.3 Definition of the building components rehabilitation program (CRP)

In this context, the CRP could be defined as the entire range of systematic actions taken in order to achieve the greatest possible efficiency in carrying out rehabilitation work on the building components of Quebec's public housing stock. An excellent planning and organizational tool, the CRP comprises, on the one hand, a budget forecasting component which takes into account the physical deterioration associated with the service life of building materials and systems. On the other hand, it will define the guidelines to be followed when such work is carried out under a comprehensive housing stock maintenance policy : consistent energy standards, acoustics, airtightness, adapting housing to specific client groups, support for the various people involved in technical housing management.

2 General characterization of housing stock

According to the SHQ's housing 1995 data bank, Quebec's public housing stock comprises : 5,540,000 m^2 of floor space, 8,682 buildings and 61,144 housing units (Figure 2). The purpose of the general characterization was to show the distribution of the housing stock in terms of floor space, number of buildings and units, according to building age from 1969 to 1994, i.e., the construction year or interest adjustment year, and according to certain characteristics such as region, acquisition method, client group, building category, use of prototypes.

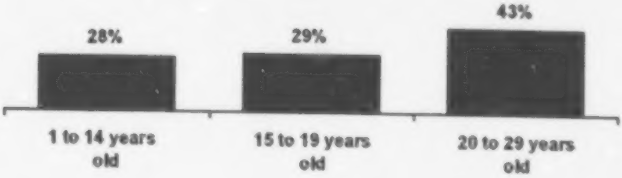


Fig. 1: Distribution of public housing floor space according to building age in 1998 (total of 8,682 buildings)

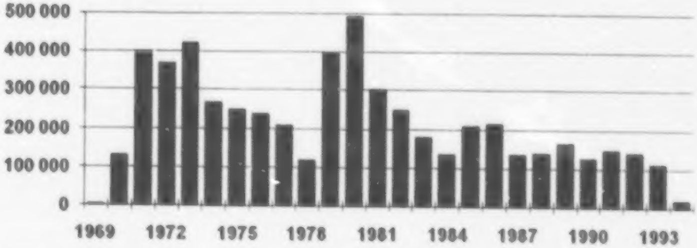


Fig. 2: Growth in Québec's public housing stock from 1969 to 1994 in m^2 (total of 5,540,000 m^2 and 61,144 housing units)

3 Specific characterization of building envelope

To identify the amount of rehabilitation work needed in the future and enable the establishment of an action plan, a specific characterization of the housing stock's physical building components had to be performed.

It was unthinkable that the 8,682 buildings and 61,144 units of the public housing stock could be visited within a reasonable time frame to measure and establish the state of health of each component. Even though the SHQ has a regular building inspection program, the purpose of the program is different from that of the current undertaking and, as a result, building inspection reports do not contain the data that is needed under the CRP. We, therefore, chose a more deductive approach consisting of analyzing the data already contained in the housing data bank and modelling the future deterioration of the various components from this data.

First, the building envelope components were examined. The siding, roofing and openings constitute, not only the first line of protection against the elements, but also, 40% of the SHQ's major repair budgets. To this end, only the most important components were included and grouped together under six "headings" based on their service life and related rehabilitation costs :

- *Heavy siding* : brick, concrete and stone.
- *Light siding* : wood, metal, vinyl and stucco.
- *Openings* : doors and windows.
- *Shingle roofing.*
- *Membrane roofing.*
- *Balconies.*

The specific characterization of these six building envelope components required numerous extrapolations based on information available in the SHQ's housing data bank. The strategy was different for each. The following is a brief description :

3.1 Calculating the surface area of siding

The housing data bank gave us data on building floor space as well as the type and relative percentage of building siding. To calculate the surface area for each type of siding, we first needed to know the surface area of the outside walls of a building. We, therefore, deduced a building's perimeter by multiplying its floor space by the applicable building category factor. We then inferred the height of the building based on the number of floors, frame type, roofing type and the presence of a basement. In this way, it was possible to calculate for each year from 1969 to 1994 the total surface area for each of the 10 different sidings specified in the housing data bank.

3.2 Calculating the surface area of openings

The housing data bank contains no data for this component. We, therefore, hypothesized, taking into account National Building Code of Canada (edition 1980, 1985, 1990) requirements and construction budgets, which had shown no variance with respect to this expensive component, that the windowed surface area of our stock was from 9% to 10% of the total housing surface area. This hypothesis was validated by calculating the windowed surface area of two multifamily buildings and two single-family buildings. The result we obtained was 9.2%.

3.3 Calculating the surface area of roofs and balconies

To calculate the surface area of roofs and balconies, we calculated the sum of the figures given in the housing data bank for each year from 1969 to 1994 and the surface areas proper to each building category.

4 Specific characterization for interior finishing

The second group of components to be examined was interior finishing components which has traditionally also constituted 40% of major repair budgets. The components selected from this group fall into the category of dwelling interior rehabilitation work and exclude painting which is considered regular maintenance work. Nevertheless, the electrical, mechanical, and plumbing work required to replace bathroom and kitchen accessories were included as part of the selected work. Here again, only the most important components were considered and grouped together under six "headings" based on their service life and rehabilitation cost :

- *Family bathroom* : vanity, sink and valving, toilet, bathtub and valving, cabinet and mirror, lighting, fan, wall finishing and flooring, plumbing and electrical system.
- *Senior's bathroom* : same components.
- *Family kitchen* : cupboards and counter, sink and valving, fan, flooring, plumbing and electrical system.
- *Senior's kitchen* : same components.
- *Family flooring* : hardwood, flexible flooring and carpeting in rooms other than the bathroom and kitchen.
- *Senior's flooring* : same components.

The specific characterization of the interior finishing components of the housing stock is determined directly from known housing data. Because a dwelling contains a corresponding bathroom, kitchen and flooring, the number and age of these components are a function of the number and age of the dwellings.

4.1 Calculating bathroom component materials

This component is similar from one dwelling to another, and there is little variance in the type and number of pieces of equipment and materials and the measurements in relation to a dwelling's floor space. As a result, the rationale "one dwelling-one bathroom" is completely applicable in this case.

4.2 Calculating kitchen component materials

To estimate the numbers for kitchen cupboards and counters, we took the same approach as we did with windows, taking into consideration National Building Code of Canada (edition 1980, 1985, 1990) and SHQ standards (Société d'habitation du Québec 1992), while factoring in the average measurements for a typical dwelling for a particular type of client.

4.3 Calculating flooring surface area

To calculate the "flooring" component, we used 75% of the average dwelling floor space according to type of client. This percentage was derived by subtracting walls and partitions as well as bathroom and kitchen flooring, which is included in the calculations for bathroom and kitchen components. It should be noted that average dwelling floor space includes private space and common space.

5 Expected life and unit cost

A cost assessment based on the expected life of the various components as surmised from our hands-on field experience and various references (Canada Mortgage And Housing Corporation, 1991; France Télécom 1991; Marshall & Swift 1995; Société d'habitation et de développement de Montréal 1994; ICF inc. 1989), allowed us to select the values shown in Table 1. Unit cost takes into account total or partial component replacement.

While realistic, these forecasts remain theoretical. Their value is strategical and lies in their usefulness for planning purposes. Only a component's actual state of deterioration, taking into account the associated risks, will determine when a component needs to be replaced. Moreover, other factors unrelated to physical deterioration such as obsolescence and updating to comply with standards may also have an influence.

Table 1: Expected life and unit cost by component

Component	Expected life		Unitcost
	Interval (years)	Replacement (%)	
Heavy siding	25	25	27,50\$/m^2
Light siding	25	100	60,00\$/m^2
Openings	25	75	262,50\$/m^2
Shingle roofing	20	100	30,00\$/m^2
Membrane roofing	25	100	45,50\$/m^2
Balconies	20	75	157,50\$/m^2
Family bathroom	20	75	1759,00\$/unit
Family kitchen	15	75	1654,00\$/unit
Family flooring	10	75	1125,00\$/unit
Senior's bathroom	25	75	1759,00\$/unit
Senior's kitchen	20	50	1103,00\$/unit
Senior's flooring	15	75	900,00\$/unit

6 Rehabilitation timetables and annual costs

While the interval constitutes the expected life of a component, i.e., average service life, we should expect the actual life to be a time interval that overlaps the average service life by a number of years. To simulate actual service life, we estimated the distribution of replacement work according to a gradual curve (Figure 3).

A rehabilitation timetable can be established for each component based on the amounts obtained from component characterization according to building age (construction year), unit cost and the replacement forecast as determined by the previously described expected life. These timetables were established for a forty-year period, starting in 1985, the first replacement year according to our distribution model which extends to the year 2025 (Figure 4). The timetables shown here correspond to the total cost of work calculated annually. Cost has been expressed in present values (constant dollars). A 20% increase was applied to take into account the outdoor design and systems components which have accounted for 20% of past rehabilitation costs.

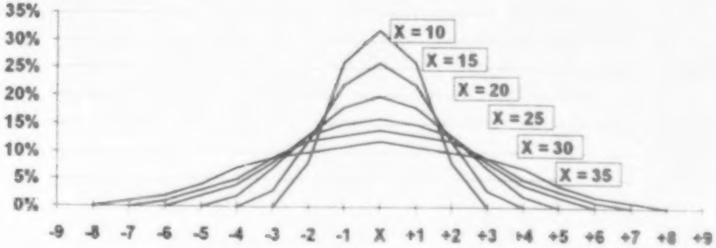


Fig. 3: Distribution of rehabilitation work according to different expected life (X : 10, 15, 20, 25, 30 or 35 years)

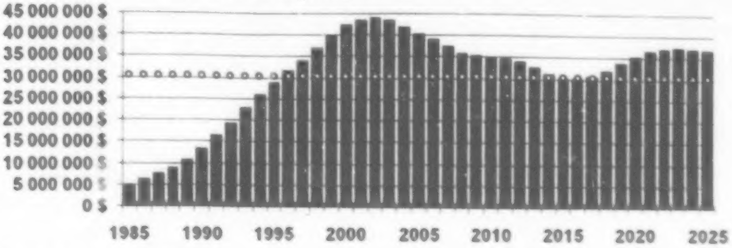


Fig.4: Annual rehabilitation work cost forecast for Québec's public housing stock (1985 to 2025 and annual average)

7 Highlights for the period 1996 to 2025

In view of the results obtained, it can be observed that the current period is characterized by increasing rehabilitation costs, continuing to rise until the year 2002 to an uneven peak of $44 million. Subsequently, costs will fluctuate around an annual average of $30 million up to the year 2025. The total cost for the period 2000 to 2005 is $255 million. The most expensive components in descending order are windows then kitchens, which are closely followed by outside walls and flooring (Figure 5).

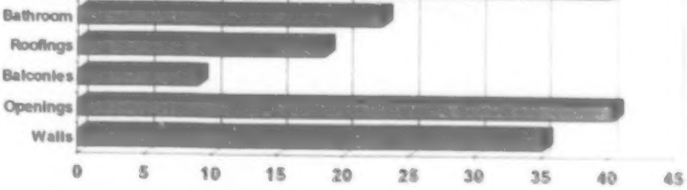


Fig. 5:Component rehabilitation cost forecast in $M for the period 2000-2005

8 Follow-up

It is urgent that guidelines be developed to enable all those concerned to deal with this situation in a concerted manner. This commitment takes on even greater importance in the context of the growing decentralization of public housing stock management.

First, a proactive planning strategy involving an awareness campaign aimed at all actors and the need for the SHQ to play a leadership role. Next, the establishment of rehabilitation criteria and methods for the components in question. Last, their integration into a rehabilitation work register.

8.1 SHQ leadership

The SHQ, both because of its mission and its position in Québec's public housing network, must play a leadership role in this program. The SHQ must develop a comprehensive approach by listening to its clients' needs, staying on top of the most advanced methods and most progressive regulations and being well aware of the physical characteristics of the public housing stock.

8.2 Rehabilitation criteria

The rehabilitation criteria must be defined for each component according to an optimum cost analysis. The criteria will constitute an assessment grid that will ensure uniform identification of rehabilitation work needs for the entire housing stock, the presentation of consistent triennial plans and the approval of appropriate budgets. All in all, a decision-making tool for both municipal housing authority personnel and SHQ officers.

8.3 Rehabilitation methods

The rehabilitation methods used should also be defined toward the same objective of achieving an optimum cost-durability ratio. Developing these standards will allow the SHQ to pass along and share its know-how in the area of construction-rehabilitation materials, methods and contract management. It will facilitate the work of the various players and provide a guarantee of quality throughout the entire process.

8.4 Rehabilitation work register

A rehabilitation work register, which is currently being studied, will allow those concerned to be continually up-to-date on the state of the housing stock, its needs and the rehabilitation objectives to be set.

8.5 Demonstration buildings

In a subsequent step, it would be wise to set up a demonstration building group that, in addition to being used to validate the present program parameters and help determine the future directions that should be taken, could also be used for experimental work in the framework of rehabilitation methods research and development initiatives.

8.6 Other building components

Because the building envelope and interior finishing have traditionally counted for 80% of major repair costs, we will now have to continue the study in order to complete the overall picture by adding outdoor design, mechanical system, electrical system and elevator components. In this way, no unforeseen actual or major costs will be overlooked during the overall planning process, undermining the promise of efficiency offered by a comprehensive approach. The CRP will be able to be put to full use.

9 Computer program for use by agents

The SHQ wishes to make available to its agents, municipal housing authorities, COOPs and non-profit organizations housing management tools that can be adapted to their particular needs. It is currently developing a computer program application which incorporates budget forecasting methods established in the context of the CRP. Designed to be user-friendly, this management assistance tool must enable managers to "personalize" the settings according to the characteristics of their buildings and produce reports in table and graphic form.

The prototype "RCF-Rehabilitation Cost Forecasting" that we are describing here is being developed using the program Excel - Version 5. It consists of three main function areas : a housing and components data bank, calculation parameters and formulas for cost forecasting (costs and schedules), and a tables and graphics function.

9.1 Housing and components data bank

The data bank contains the following essential data for each building : identification, construction date, barring the service date for each building component, a list of the components and quantities for each. Optional data consist of secondary identification, building category, and for each component, a description, the group it belongs to, service date, service life, and rehabilitation cost in standard units. The program will attribute default values for the last four pieces of information which the user can modify as needed.

Initial data entry can be performed in two ways : direct entry by the user or a data transfer request from the housing data bank (HDB). In the latter case, the quantities for the various components are calculated automatically based on the characteristics of a building. This data can subsequently be changed by the user. Then using the dialog box from the program's main window, users can access the data bank to consult or modify the list of buildings, building data sheet (list of components), or component data sheet (group, description, quantity, unit, service date, service life and unit cost).

9.2 Cost forecasting and schedules

Total quantities by component and year are calculated by the program. Similarly, cost forecasts and schedules extending to the year 2025 are established using array formulas, based on service life and unit costs. Accordingly, calculations update the results as the data bank grows and is modified.

9.3 Presentation of data in table and graphic form

As requested by a user, the results are presented in table or graphic form, showing detailed data or selected data for a building, building group (according to age, clients, etc.), component, component group (envelope, interior finishing, etc.), year or specific period (Figure 6 & 7).

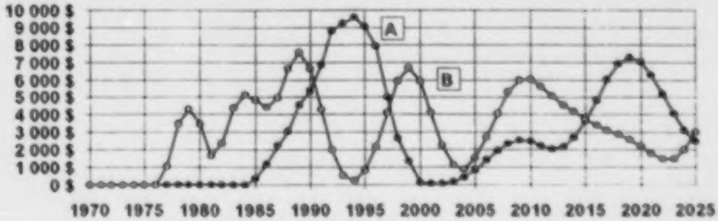


Fig.6: Example of "RCF" graphic form – Annual rehabilitation cost forecast for components A & B

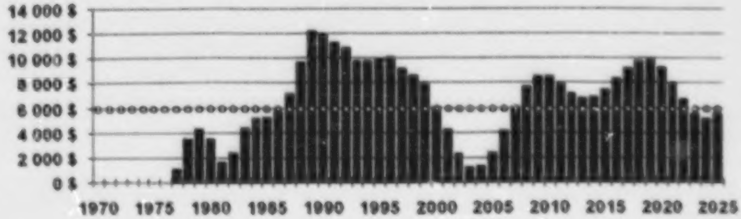


Fig.7: Example of "RCF" graphic form – Total annual rehabilitation cost and average curve

10 Conclusion

This program initiative, which is based both on scientific theory and first-hand experience but which is entirely pragmatic, was undertaken in response to the very legitimate concerns of the SHQ, the biggest real estate owner in Québec. The ultimate goal is to have even better data and tools in order to be able to make the best possible decisions.

While the degree of accuracy of the present model remains to be demonstrated, the essence of the initiative resides in the following facts which must be emphasized in this conclusion : at a point in time when Québec's public housing stock has practically reached "zero" growth, its physical characteristics are quantifiable, actual service life are foreseeable and replacement costs are predictable. By becoming aware and being prepared, we can stay on top of the situation. After all, "managing is foreseeing"!

Our objective will have been achieved if we succeed in conveying our concerns and our findings to all the actors concerned. Their contribution will be indispensable in order to validate and confirm the present hypotheses and implement appropriate solutions.

11 References

Canada Mortgage and Housing Corporation (CMHC). (1991) Life-Cycle-Costing Model. Unpublished software.

Canada Mortgage and Housing Corporation (CMHC). Formulaire pour le calcul de la réserve de remplacement. Unpublished form.

France Télécom. (1991) *SIMUL.* Logiciel de simulation budgétaire du maintien de l'actif. Unpublished software.

Marshall & Swift. (1995) *Valuation Quarterly.*

National Research Council Canada. Canadian Commission on Building and Fire Codes. *National Building Code of Canada, edition 1980, 1985, 1990.*

Société d'habitation et de développement de Montréal (SHDM). (1994) Formulaire pour l'inspection de l'enveloppe du bâtiment. Unpublished form.

Société d'habitation du Québec. (1992) Cadre normatif SHQ, partie 2 - Prescriptions. Unpublished document.

ICF inc. (April 1989) *Future Accrual of Capital Repair and Replacement Needs of Public Housing. Final report.* Washington, D.C. U.S. Department of Housing and Urban Development. 1 v.

162 REHABILITATION AND THE COSTS TO SUSTAIN DWELLING SERVICES

I.M. Johnstone

The University of Auckland, New Zealand

Abstract

Although decisions to undertake rehabilitation of dwellings are based on private benefits and costs, spillover social benefits ensue because rehabilitation reduces the annual replacement rate of a housing stock below that which would be required otherwise to sustain a set quantity and quality of dwelling services. This paper uses a simulation model to make exploratory estimates of the potential for further reductions in the costs to sustain dwelling services. The model uses data and parameters based on New Zealand housing stock. The potential for further reductions in costs is substantial should a housing stock be stationary, but is insignificant at high expansion rates. A decline in the expansion rate of a housing stock has a greater impact on reducing costs in the long run than an increase in current levels of rehabilitation. The durability of the structural system used by dwellings ultimately limits the service life of dwellings and hence the potential for further reductions in costs.

Keywords: annual replacement rate, durability of structural system, dwelling services, housing stock, rehabilitation, simulation model, social benefits, total average costs.

1 Introduction

Seip (1979), a Norwegian economist and former Minister of housing, admonished that housing in the past had concentrated too much on new development to the neglect of the resources embodied in existing dwellings. The extent of these resources is considerable. For example, dwellings formed over 23% of the total value

Durability of Building Materials and Components 8 (Volume Three). *Edited by M.A. Lacasse and D.J. Vanier*. Published in 1999 by NRC Research Press, Ottawa ON K1A 0R6, Canada. ISBN 0-660-17742-0

of New Zealand's capital stock of buildings, infrastructure, plant, and equipment in 1989 (Philpott 1992). Seip urged that future housing policies should be based on the optimum use of these resources. There is a commonly held viewpoint that free market economic forces alone promote an optimum use of resources, including those resources embodied in existing buildings. The basis for this viewpoint is summarised as follows.

Rehabilitation of buildings can be rationally justified only if the costs of doing so are equal to or less than an increase in the exchange value of the property. The level of rehabilitation is optimised when marginal costs equal marginal benefits. A partial level of rehabilitation may be optimal, irrespective of budgetary constraints, when building components undergo incurable depreciation. The costs of full reversing curable depreciation are less than or equal to the consequent value that will be added to the exchange value of the property, whereas the costs of fully reversing incurable depreciation is greater. Returns on a building may therefore be maximised while the quality of services declines.

Rises and falls in land values have an impact on the optimum level of rehabilitation. A rise in land values may justify full and complete rehabilitation, an upgrade, or an extension. When land values are sufficiently high, demolition and replacement or redevelopment may be justified. The economic life of a building reaches an end when the market value of the property plus the costs of demolishing and clearing the site are less than the value of the cleared site in a new and higher use. A building can still be technically efficient beyond its economic life by continuing to earn net annual returns. If redevelopment has not taken place by the time net annual returns are zero, then the property is left derelict.

Expenditure on rehabilitation does not guarantee an extension of services. Situations exist where buildings undergo extensive rehabilitation and are demolished shortly afterwards so as to enable redevelopment. Fully sunk costs are irrelevant and should not enter into economic decision-making because they represent no opportunity for choice. All economic decisions are made at the margin by weighing additional costs against additional benefits. Demolition and replacement of existing buildings which provide adequate services may appear to be wasteful of resources, but the alternative of foregoing opportunities which generate greater value is more wasteful.

What the above viewpoint overlooks is that what counts as a benefit or a loss to individuals or sectors within an economy does not necessarily count as a benefit or loss to the economy as a whole. There can be spillover social costs to a community which result from collective individual action, as in the example of the Tragedy of the Commons given by Hardin (1977), and there can be spillover social benefits. By extending the life expectancy of dwellings, each additional cycle of rehabilitation reduces the annual replacement rate of a housing stock below that which would be required otherwise to sustain a set quantity and quality of dwelling services. It is possible to further reduce the costs to sustain dwelling services by increasing current levels of rehabilitation. A reduction in the costs of supplying a good, such as dwelling services, can be directly translated into a benefit for society when there is a consequent increase in the consumer surplus (Mishan 1988).

This paper uses a simulation model to make exploratory estimates of the potential for further reductions in the costs to sustain dwelling services. The model uses data and parameters based on New Zealand housing stock. Factors which limit this potential are identified and incentives to enable and encourage further reductions in costs are discussed.

2 Mortality of the New Zealand housing stock

The mortality of housing stock is central to the dynamics of dwelling services. Measures of mortality include average life expectancy upon entry and life span. These measures are more appropriately referred to as average service life and service life span when applied to housing stock.

I previously estimated (Johnstone 1994) the average service life of New Zealand housing stock to be 90 years by using a simulation model which effectively links a series of generation, or longitudinal, life tables. The mortality experienced by the New Zealand housing stock between 1860 to 1980 had been dynamic in that the probability of loss of dwellings from each cohort had simultaneously increased and decreased with each increase and decrease in the expansion rate of the housing stock. Estimates of life expectancy are based on the assumption that mortality which applied in the past will continue in the future. Given the same assumption, the average service life of New Zealand dwellings would increase from 90 years to 130 years should the expansion rate of the housing stock decline to zero.

I define the service life span of a housing stock to be that age beyond which less than 0.1% of the oldest dwelling cohort still stands and provides dwelling services. This definition based on Shryock et al. (1973) enables sensible comparisons of the service life spans of different housing stocks as exceptional dwellings are excluded. The current service life span of New Zealand dwellings is 140 years.

3 Simulation model

The simulation model of periodic rehabilitation used in this paper estimates the total average costs to sustain one unit of dwelling services. Costs include that of new-build construction which adds to the size of a housing stock, maintenance, rehabilitation, demolition and replacement. Costs are expressed in construction units (cu), the costs to construct one dwelling. Dwelling services are expressed in dwelling service year equivalents (sye), the services provided by a dwelling over one year after adjusting for depreciation. The model is an extension of my simulation model of single-cycle rehabilitation (Johnstone 1998a). A mathematical description of the model is contained in Johnstone (1998b).

Dwellings are assumed to be homogeneous. Heterogeneity can be taken into account by constructing separate models for distinct classes of dwellings. The services of Ricardian land are separated from the services provided by improvements to land and are not modelled. Real costs of construction are assumed to remain constant over time. It follows that the long run supply curve of the construction industry is perfectly elastic and returns to scale are constant as the construction industry expands.

Parameters are set to extreme limits in order to estimate the full impact of periodic rehabilitation. Dwellings undergo 'full' and complete rehabilitation to the extent that depreciation of dwelling services and the probability of loss of dwellings are fully reversed. The effective age of dwellings is zero immediately after undergoing full rehabilitation. Entire dwelling cohorts are set to undergo full rehabilitation at regular cycles. Partial rehabilitation is not modelled. The costs of full rehabilitation are set to be the maximum that can be justified as estimated by my actuarial model of rehabilitation versus new construction (Johnstone 1997). If full rehabilitation can take place within a maximum justifiable budget, then private investment is better diverted from new housing to rehabilitation of existing dwellings. The real discount rate is set to be 6.0%.

Depreciation of dwelling services is set to be that based on an inverted 'S' curve as described by Baer (1991). Annual maintenance costs are set to be constant at 1.0% of the costs to construct a dwelling. This level of maintenance is based on a sample of New Zealand dwellings (Johnstone 1998a).

The simulation model is driven by a dynamic mortality regime which applies for a primary housing stock in which no rehabilitation takes place. The service life span of a primary housing stock is 80 years when stationary, 55 years when the expansion rate is 1.0% per year and 50 years when the expansion rate is 2.3% per year. The mortality regime of a housing stock which undergoes full rehabilitation is an amalgam of the primary mortality regime and reversals in probability of loss with each cycle of rehabilitation.

The optimum interval between each cycle of full rehabilitation is the shortest interval at which it is feasible to undertake full rehabilitation. This interval is set to be 20 years. The corresponding maximum justifiable budget is 26.6% of the costs to construct a new dwelling. Expenditure on full rehabilitation is set to be the same regardless of the expansion rate. The number of cycles of full rehabilitation are increased under each expansion rate so that the service life span of the simulated housing stock is as close as possible to the service life span of the New Zealand housing stock with increments of 100 years thereafter.

4 Results and analysis

The results of a primary housing stock are listed in table 1. Total average costs of a primary housing stock which undergoes expansion at the constant rate of 2.3% per year are 63.9% greater than that of a stationary primary housing stock. A stationary housing stock is able to provide dwelling services at a lower cost for the following reasons.

Table 1: Results of primary housing stock

	Service Life Span (years)	Average Service Life (years)	Total Average Costs (cu/sye)	Marginal Increase in TAC (%)	Annual Replacement Rate (%)
Expansion rate = 0%	80	47	0.0360		2.13
Expansion rate = 1.0%	55	36	0.0485	34.7	2.35
Expansion rate = 2.3%	50	33	0.0591	23.1	2.08

Expenditure on new construction forms a new dwelling cohort that yields dwelling services which are fully realised over future time intervals. When a housing stock is stationary and stable, the quantity and quality of dwelling services provided by each dwelling cohort within the housing stock over the same time interval are in a one to one correspondence with the quantity and quality of dwelling services provided by a single dwelling cohort over successive time intervals. The dwelling services yielded by expenditure on new construction (replacement construction only in the case of a stationary housing stock) are effectively realised over the same time interval. In contrast, when a housing stock undergoes expansion, increasingly larger expenditures on new construction (new-build and replacement construction) are made over successive time intervals before the yield of any previous expenditure has been fully realised. Total average costs are accordingly larger.

Table 2 lists the total average costs of a housing stock in which entire dwelling cohorts undergo full rehabilitation. The average annual replacement rate of dwellings as a percentage of the size of New Zealand housing stock between 1921 to 1981 was 0.39% per year and the average annual expansion rate of the housing stock over the same period was 2.3% per year (Johnstone 1994). Although the full extent and level of rehabilitation undertaken within the New Zealand stock in the past is unknown, it is certain that entire dwelling cohorts did not undergone full rehabilitation and that the mortality of all dwellings was therefore not full reversed with each cycle of rehabilitation. The annual replacement rate of the simulated housing stock under the same expansion rate and service life span as above should therefore be less than 0.39% per year, provided the primary mortality regime used by the simulation model is realistic. The annual replacement rate of the simulated housing stock is 0.27% per year, a rate which is 70% of the average annual replacement rate of the New Zealand housing stock.

The annual replacement rate of a primary housing stock which undergoes expansion at the rate of 2.3% per year is 2.08% per year, a factor of 5.3 times greater than the average annual replacement rate of the New Zealand housing stock. A precise estimate of the decrease in total average costs due to partial rehabilitation cannot be made because the full costs of rehabilitation have not been enumerated. A lower limit can be estimated by assuming that full rehabilitation had taken place every

20 years and that the maximum justifiable budget had been fully expended at each cycle. On this assumption, partial rehabilitation undertaken within New Zealand housing stock has reduced total average costs by at least 6%. The annual costs of rehabilitation used in this estimate are 70% of the annual costs of new construction (new-build and replacement). The value of additions and alterations estimated for building consent purposes has averaged 14.4% of the value for new construction between 1921 to 1989 (Statistics New Zealand 1921-1990). The full extent of partial rehabilitation may be double that work undertaken with a building consent. If the costs of partial rehabilitation were assumed to form 35% of the costs of new construction, then an estimate of the reductions in total average costs due to partial rehabilitation would be 22%.

Table 2: Results of full rehabilitation

	Service Life Span (years)	Average Service Life (years)	Total Average Costs (cu/sye)	Marginal Decrease in TAC (%)	Annual Replacement Rate (%)
Expansion rate = 0%					
	140	106	0.0286		0.94
	240	202	0.0260	9.1	0.49
	340	296	0.0252	3.1	0.34
Expansion rate = 1.0%					
	135	110	0.0356		0.52
	235	195	0.0336	5.6	0.21
	335	271	0.0331	1.5	0.13
Expansion rate = 2.3%					
	149	121	0.0456		0.24
	249	196	0.0450	2.2	0.15
	349	259	0.0450	0.0	0.14

The potential for further reductions in costs is substantial should a housing stock be stationary, but is insignificant at high expansion rates. Total average costs of a stationary housing stock decrease by 9.1% should additional cycles of full rehabilitation extend the service life span from 140 years to 240 years. In contrast, total average costs decrease by 2.2% when the expansion rate of the housing stock is 2.3% per year and the service life span of 149 years extends by 100 years. Greater reductions in total average costs would be possible should full rehabilitation be undertaken within the maximum justifiable budget.

Reductions in total average costs which ensue from each additional cycle of rehabilitation are subject to diminishing returns. This is because there are fewer surviving dwellings at the start of each cycle that can take advantage of rehabilitation. Diminishing returns are more pronounced when a housing stock undergoes expansion because there are proportionately fewer older dwellings that are able to take advantage of rehabilitation.

A decline in the expansion rate of a housing stock has a greater impact on reducing total average costs than an increase in current levels of rehabilitation. For example, if current levels of rehabilitation remain unchanged and entire dwelling cohorts were to undergo full rehabilitation, then an immediate decrease in the expansion rate from 2.3% per year to 1.0% per year would reduce total average costs by approximately 20% in the long run. Reductions in costs would be gradual due to the time lags inherent in the dynamics of housing stock.

The differential costs of using more durable structural systems have not been included in the model. Parallel estimates of the break-even costs of using more durable structural systems within a stationary housing stock are given in brackets. If the service life span of the housing stock should extend from 140 years to 240 years and the expansion rate is 1.0% per year (0% per year), then decreases in total average costs would completely dissipate should the costs of using a more durable structural system be 1.9 times greater (3.8 times greater) than that of the less durable system.

5 Discussion

Rehabilitation of dwellings reduces the total average costs to sustain a unit of dwelling services. If no rehabilitation had taken place within the New Zealand housing stock in the past, then annual replacement rates would be as much as 5 times greater and total average costs would be at least 6% and perhaps as much as 22% greater.

Further reductions in total average costs can be gained by increasing current levels of rehabilitation. The potential for further reductions in costs is substantial should the housing stock be stationary, but is insignificant at high expansion rates. A decline in the expansion rate of the housing stock has a greater impact on reducing costs in the long run than an increase in current levels of rehabilitation. A combination of a decline in the expansion rate and an increase in current levels of rehabilitation would dramatically reduce the costs to sustain dwelling services.

Further reductions in the costs to sustain dwelling services can be translated into social benefits. Apart from an increase in the consumer surplus, spillover social benefits include a decrease in the throughput of resources, a reduction in the rate of formation of waste products from demolition, and a reduction in the impact of manufacturing and construction processes on the environment. Some social benefits would be immediate, such as a decrease in levels of pollution, whereas others would gradually increase over time. All social benefits would be made possible by reducing the rate of draw down on the resources embodied in existing dwellings.

Although departures from a housing stock are the end result of an economic process, it is the durability of the structural system used by dwellings that ultimately limits the service life of dwellings and hence the potential for further reductions in costs to sustain dwelling services. For example, although isolated rotting timber piles, bearers, floor joists, wall studs, rafters, and the like can be replaced, an entire lightweight timber framing system has to be replaced when general structural failure occurs.

The contrast between the durability of the structural systems commonly used by New Zealand and British dwellings and their corresponding service life spans is of note. The predominant structural system used in New Zealand is lightweight timber framing (Nana 1981), a system that is prone to decay, whereas the structural walls of British dwellings are predominantly of brick and stone, both durable materials. The service life span of New Zealand dwellings is 140 years whereas the service life span of British dwellings is at least 273 years. Riley (1973) estimated that 0.1% of the British housing stock had been constructed prior to 1700.

New Zealand has a performance based building code that requires those items which contribute to structural stability to have a service life of 50 years (Building Industry Authority 1992). This service life falls well short of the 90 year average service life and 140 years service life span of the housing stock. There are two issues here. The first is that new structural systems, such as galvanised steel framing, need only comply with the shorter service life of 50 years. The second is that the prediction of the long run durability of building components based on accelerated ageing is fraught with difficulties (Masters 1987). The most reliable predictor of durability is a successful past history of performance. Lightweight timber framing and brick and stone structural systems have already demonstrated their ability to match and exceed a service life of 140 years. The prudence of allowing structural systems with unproven long run durability to enter the housing stock and setting a minimum service life which falls well short of the current average service life and service life span of the housing stock should be closely examined.

When there are spillover benefits for society, it is worthwhile for society to provide incentives to increase spillover social benefits to the point where the marginal social costs of providing incentives equal the marginal social benefits that ensue. Incentives to enable and encourage an increase in current levels of rehabilitation include charges and subsidies in the form of grants, loans, and tax allowances.

Charges levied on the demolition of dwellings would retard the rate of demolition and replacement and encourage recycling of demolition wastage to offset the costs of demolition.

Until recently, the lowest income groups in New Zealand have either rented state owned dwellings at subsidised rents, purchased state owned dwelling with subsidised loans, or purchased new housing with subsidised loans (Lowes 1990). The process of filtering down has been bypassed, but should take place in the future due to recent changes in governmental policies. Future assistance to low income families could take the form of grants to undertake rehabilitation.

A random survey of 400 New Zealand dwellings has revealed that deferred maintenance averaged NZ$3,200 per dwelling (Page et al. 1995), or almost three times the average costs of annual maintenance. Those homeowners who have a limited income are more likely to defer maintenance and not undertake rehabilitation. Home improvement loans could be made available to these homeowners at subsidised interest rates. One sector of the community that could benefit the most from home improvement loans is that of the elderly. For many, their home represents their sole store of savings. Rather than allow these houses to sink into disrepair, a loss that ultimately a national loss, reverse mortgages for the purposes of home improvements should be made more readily available to the elderly at reasonable terms. Reverse mortgages also fulfil the role of a superannuation scheme.

Depreciation allowances could be modified to encourage rehabilitation by using diminishing value depreciation schedules which, in practice, apply to the effective age of buildings. Evidence of undertaking rehabilitation would result in a reversal to a higher depreciation rate. The issue of whether depreciation allowances should apply to owner-occupied dwellings is related to the wider issue of tax deductions of interest on mortgages and tax on imputed rent.

The effectiveness, efficiency, and equity of the above incentives to undertake higher levels of rehabilitation would need to be carefully examined before implementation. Baer (1991) cautions that the "when" or correct timing of intervention is equally as important as the "how". The importance of recognising local circumstances should also not be overlooked.

The simulation model used in this paper is based on an assumed schedule of primary depreciation and the primary mortality regime used to drive the model has yet to be fully validated. The exploratory estimates in this paper confirm that the model exhibits realism, but in order to improve precision, full validation of the primary schedule of depreciation and the primary mortality regime of housing stock needs to be carried out. The set of assumptions that underpin the model can, and should, be modified or relaxed. For example, full rehabilitation is assumed to take place at regular intervals whereas, in practice, partial rehabilitation takes place at irregular intervals.

6 References

Baer, W.C. (1991) Housing Obsolescence and Depreciation, Journal of Planning Literature, Vol. 5, pp. 323-332.

Building Industry Authority (1992) *The New Zealand Building Code Handbook and Approved Documents.* Standards New Zealand, Wellington.

Hardin, G. (1977) The Tragedy of the Commons, in *Managing the Commons* (eds. G. Hardin and J. Baden), W H Freeman, San Francisco, pp. 16-30.

Johnstone, I.M. (1994) The Mortality of New Zealand Housing Stock. *Architectural Science Review*, Vol. 37, pp. 181-188.

Johnstone, I.M. (1997) An extended actuarial model of rehabilitation versus new construction of housing. *Journal of Property Finance*, Vol. 8, pp. 126-133.

Johnstone, I.M. (1998a) The optimum timing and maximum impact of full rehabilitation of New Zealand housing stock. *Environment and Planning A*, Vol. 30, pp. 1295-1311.

Johnstone, I.M. (1998b) Periodic rehabilitation and the economic life span of housing stock. *Proceedings of the International Conference on Buildings and the Environment in Asia, School of Building and Real Estate, National University of Singapore, Singapore.* pp. 29-31.

Lowes, N.M. (1990) The Effect of Central Government Policy on the New Zealand House. *NZ Real Estate*, September 1990, pp. 31-37.

Masters, L.W. (1987) Service life prediction: a state-of-the-art report. *Building Research and Practice*, September/October, pp. 292-296.

Mishan, E.J. (1988) *Cost – benefit analysis: an informal introduction*, 4th edition, Routledge, London.

Nana, N. (1981) *Urban Housing Stock in New Zealand, Volume 10: New Zealand Totals*, Research Paper 81/6, National Housing Commission, Wellington.

Page, I.C., Sharman, W.R. and Bennett, A.F. (1995) *New Zealand House Condition Survey 1994*, SR62, Building Research Association of New Zealand, Wellington.

Philpott, B. (1992) *Provisional Estimates of New Zealand Real Capital Stock by SNA Production Groups 1950 – 1990*, PEP Internal Paper 233a, Economic Group, Victoria University of Wellington, Wellington.

Riley, K.M. (1973) An Estimate of the Age Distribution of the Dwelling Stock in Great Britain. *Urban Studies*, Vol. 10, pp. 373-379.

Seip, H. (1979) Building in Economic Terms. *Building Research and Practice* March/April 1979, p. 90.

Shryock & Siegel and Associates (1973) *The Methods and Materials of Demography: Volume 2*, US Government Printing Office, Washington DC.

Statistics New Zealand (1922-1990) *Building Statistics Series 1922-1990*, Statistics New Zealand, Wellington.

163 FORECASTING THE RUNNING COSTS OF SPORT AND LEISURE CENTRES

R.J. Kirkham, A.H. Boussabaine, R.G. Grew, and S.P. Sinclair

University of Liverpool, UK

Abstract

The cost of provision and maintenance of safe and comfortable conditions for the activity taking place in any leisure centre are the main predominant factors in the prediction of running costs. This paper describes the fundamentals associated with running costs in leisure centres and then investigates all 19 sports centres in Liverpool using data elicited from the Liverpool Leisure Services Directorate. The energy operating costs were analysed using statistical methods. Six models were developed to predict total energy costs. Testing and validation results showed a high level of accuracy of models. The models would be of use to professionals involved in feasibility studies of different scenarios at the design

Keywords: running costs, leisure centres, cost modelling, maintenance, statistics

1 Background

Maintenance contributes significantly to the total cost of a building. It is important though to differentiate between running costs and maintenance costs as many confuse the two. Running costs (or operational costs) infer all costs associated with enabling the building to function – other than maintenance costs. Mills (1994) classified these costs into four sub-groups;

Group 1: rental costs, costs of capital used during procurement, rates, taxes and Building insurance
Group 2: utilities, specialist communications and network systems
Group 3: tertiary services (porters, cleaners, telephone, fax etc.)
Group 4: staff employed to work in the building

Durability of Building Materials and Components 8 (Volume Three). *Edited by M.A. Lacasse and D.J. Vanier*. Published in 1999 by NRC Research Press, Ottawa ON K1A 0R6, Canada. ISBN 0-660-17742-0

Holmes (1994) draws the distinction between the two types of maintenance, response and maintenance. Figure 1 highlights this and shows the sub groups derived from them. Response maintenance can be divided into normal maintenance and emergency maintenance, the terms thus indicating the priority given to the work required. All organisations should draw up an emergency response list to enable problems to be prioritised easily. Response maintenance is usually initiated by the occupier and will be categorised by a number of factors such as type of work required, nature of fault and seriousness. This coding of work gives vital data on response maintenance thus enabling future budgets to be manipulated to take account of future maintenance demands.

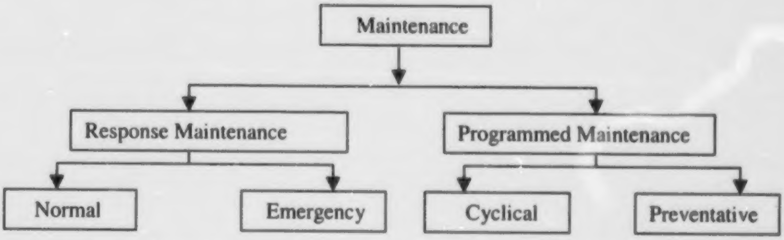


Fig. 1: Types of maintenance (Holmes 1994)

Programmed maintenance (or planned maintenance) can again be categorised into two further sub-divisions. Cyclical maintenance is that which is carried out irrespective of the condition of the elements. Preventive maintenance is condition dependent and really should only be carried out when an element has reached its optimum life span or under the recommendations of the manufacturer. It should also be employed when it is likely that the element will deteriorate seriously unless attended to.

In a report prepared for the Building Research Establishment, Burt (1978) estimated that for non-domestic buildings, the average annual running costs are about the same as the annual repayments of the mortgage or other such financial package. Flanagan and Norman (1989) also investigated the cost of running an office building. They estimated that for every £100 spent on repaying the capital cost of the site and building, £138 is spent on running costs. Figure 2 shows how the running costs are distributed. These amounts were calculated over a 40-year period using a 2% discount rate. The chart shows us that maintenance costs account for 12% of the total life cycle of the building.

Mills (1994) highlights the importance of design decisions upon the likely maintenance costs that will arise in the future. The design decisions made will dictate the likelihood of component failure etc. and how the incidence of use will place particular demands upon the building structure and fabric.

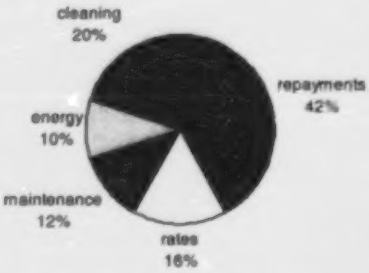


Fig. 2: Life cycle costs of an office building (Flanagan and Norman, 1983)

Leifer (1997), in a study of the economics of building ownership draws attention to the fact that maintenance costs become increasingly onerous as the wear and tear on the fabric and structure (including services) increases. Attention was drawn to the bathtub model shown in Fig 3, showing component failure during and after the defects liability period.

It also highlighted how maintenance and operating costs can cumulate to the extent where ownership is uneconomic and refitting or demolition needs to be considered.

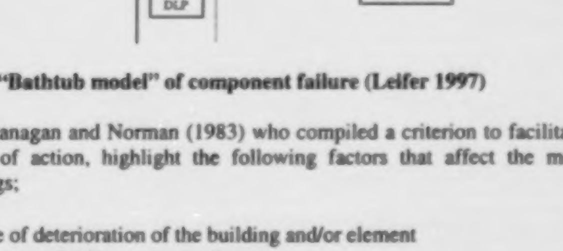


Fig. 3: "Bathtub model" of component failure (Leifer 1997)

Flanagan and Norman (1983) who compiled a criterion to facilitate the correct choice of action, highlight the following factors that affect the maintenance of buildings;

- Rate of deterioration of the building and/or element
- The cost of different types of repair
- The disruption and disturbance to the building occupants and time required for repair

- The relationship between the physical life of the repair and the required physical, functional and economic life of the building.

The purpose of this paper is to present a series of models developed to forecast the cost of energy for sports centres. The models take into account floor area and number of users as the main input to the models.

The paper reviews the factors, that influence energy consumption, and discusses the techniques used to model maintenance and running costs. The paper compares the forecasting accuracy of the developed models and proposes a non-linear method to forecast energy costs for sports centres based upon floor area and user.

The paper aims to raise awareness of the need to control the energy usage in sports centres and how that need can be effectively and efficiently met. In addition, the use of modelling to predict energy costs will be covered as well as an alternative method, Neural Network Analysis. In all, the paper will study all the stages in considering and implementing a cost forecasting system that will enable professionals to consider the likely energy costs of a particular design solution prior to construction (or refurbishment) taking place.

2 Modelling maintenance and running costs

Over the past two decades, all those involved in the procurement and running of buildings have become increasingly aware of the importance of early stage advice on the cost implications of design decisions. Decisions made during design can have a significant impact upon the future running and maintenance costs of buildings; this is especially true of high occupancy buildings such as sports centres.

Much published work exists on cost modelling, all trying to clarify what can be a potentially confusing and arguably an inherently academic field. Brandon (1982) and Bowen and Edwards (1985) initially brought to the forefront the need to produce cost models of a more realistic nature. Ashworth (1994) and Seeley (1985) reported most of the standard cost models in use and Ferry and Brandon (1991) also added possibly some of the less used ones. Previous studies by Ashworth (1985), Skitmore (1991), Newton (1991) and Fortune and Lees (1996) have collected together comprehensively all popular and less well used models currently in use within the industry. In fact the latter contained a survey of NorthWest England quantity surveying firms, investigating the incidence of use of the various models. Fortune and Lees (1996) and Fortune (1998) classified the various models into 5 main groups. This study recognises these models and adds to them artificial intelligence as an important tool for modelling running costs.

3 Selection of a model

All models rely to some extent on assumptions, whether explicit or implicit. To assess the viability of a model, the user needs to have access to and understand the assumptions, which contribute to it. Unfortunately, where the assumptions are built in, it is difficult to assess and evaluate the model in question. A key issue to consider here also is that cost will always be uncertain. Therefore, the user must distinguish between those that include a formal measure of uncertainty (stochastic methods) and those that do not (deterministic).

The selection of a model should be based on the following attributes;

- The characteristics of data to be employed – quantitative, qualitative, large, small
- General knowledge of the problem to be modelled
- General knowledge about the boundary conditions of the model
- Errors that the model can generate
- Input and output targets and possible consequences
- Understanding of accuracy, reliability, validity, confidence and sensitivity of the model to be selected

4 Characteristics of sport centres

The provision and maintenance of a safe and comfortable environment is a basic requirement of any building service installation. However, the exact interpretation of this isn't very clear, but the Sports Council for England has published a range of documents, which give guidance on service provision for a wide range of sports and recreational facilities. These guides reveal that the various activities that take place within sport centres require in most cases, different types of service provision. Obviously them, the type of activities taking place within the sport centres will have a significant impact upon the energy requirements and costs of the building. The clear implication is then that when attempting to derive some form of cost model, it is important to consider the activities taking part within the building as clearly, a simple energy cost per m^2 approach will not yield accurate results. To give some kind of perspective on energy costs, the table below gives service requirements for different sporting activities.

The Building Research Energy Conservation Support Unit (BRESCO) estimated that total energy consumption could be reduced by as much as 15% by implementation of energy efficient measures. This could amount to saving the sector somewhere in the region of £90million and reduce carbon dioxide emissions by about 1.4 million tones per year. On average, sport centres consume £70,000 worth of fuel per year so assuming 15% could be saved, this means a reduction of around £10,000.

Apart from the obvious financial benefits, implementing energy conservation measures can also lead to reduced maintenance cost and a safer, more comfortable environment.

5 Data Collection

In order to develop a cost model, a sample of data was collected from Liverpool City Council – Directorate of Leisure Services. The data was collected by documentary sources as opposed to others highlighted by Robson (1993) such as direct observation, mailed questionnaire and interviewing.

Table 1: Service requirements of sports centres (EEO – Best practice for design of sports centres)

Facility	Heating (°C)	Ventilation	Lighting (lux)
Multi-purpose	12-18 active 18-21 non active	8-12 l/s/person	Recreation 300 Club/county 500
Swimming pool	Air temp 1°C Higher than water	12 l/s/person	200-300
Fitness centre	16-18	10-12 ac/h	300min
Weight training	12-14	10-12 ac/h	300av
Squash courts	16-18	10-12 ac/h	380 no spectators
Ancillary halls	15 sports 21 non-sports	3 ac/h sports 1.5 ac/h	300
Outdoor changing rooms	20-25	10 ac/h	150
Reception and administration	16-20	>3 ac/h	250
Crèche	21	>3 ac/h	250
Refreshment and bars	18	Not less than 8/l/s/person – check with L.A.	250

Fellows and Liu (1997) describe the fundamentals associated with data collection and in particular highlight the need to investigate the nature of data and collection mechanisms in order to be aware of the limitations of the data and their validity, notably comparability. As mentioned previously, data was extracted directly from a database provided by Liverpool Council. This method of data collection has the advantage of "value-free" research. That is to say that the work is unaffected by the beliefs or intentions of the researchers or data sources. Similarly, as the research is not based upon the data collected from previous work, then the actual data will be raw and will not have been tailored for other purposes.

6 Modelling total energy costs of sport centres

Total energy costs for sports centres can be modelled in a general inpuput/output relationship of the form:

$$y = f(x) \tag{1}$$

Where x is the m-dimensional input (energy consumption) and y is the n-dimensional real output (total energy cost). The relationship between input and output is determined by a real world mechanism (i.e., the state of the building and condition of use). Therefore, the total cost of energy in sports centres can be envisaged as a system governed by a continuum of variables. In principle, if the complete state of the building usage information are known at some point in time, it should be possible to predict total costs of energy consumption.

This is a complicated system to model mathematically, due to the complexity of the variables involved in the building of the model (see energy consumption influencing factors). This problem might be simplified by using a finite collection of energy consumption parameters (collected over a period of time) as the input and the total cost of energy as the output of the state of the system.

Therefore, this work uses two parameters of energy consumption, i.e. floor area, number of users as input to the system to predict total cost. This relationship can be modelled in the following function:

$$y(total\,cost) = f(floorarea, user) \text{ or}$$

$$y = f(x_1 x_2) \tag{2}$$

Given the floor area and number of users over a period of time, in this case one year, it is possible to predict the total cost of energy over the same period. Many techniques can be employed to estimate the parameters or coefficients of the relatives in equation 1.

In this work, two methods were employed. First it was assumed that the relationship in equation 1 is of a linear type if the following form:

$$y = c + b_1 x_1 + b_2 x_2 \tag{3}$$

Then multiple linear regression (an expansion of the least square regression method in that it involves more than one independent variable), is used to determine the coefficients.

Second, a non linear form for equation 2 was investigated, because some of the variables might have a non linear relationship with the total cost of energy. In total, five non-linear combinations were developed and tested. The equations of these models are as follows:

$$y = c + e^{b_1 \log x_1} + e^{b_2 \log x_2} \tag{4}$$

$$y = c + e^{b_1 \log x_2} + e^{b_2 \log x_1} \tag{5}$$

$$y = c + e^{b_1 \log x_1} + b_2 \log x_2 \tag{6}$$

$$y = c + b_1 (\log x_2)^{a_1} + b_2 \log x_1 \tag{7}$$

$$y = c + b_1 (\log x_2)^{a_1} + b_2 (\log_1)^{a_2} \tag{8}$$

6.1 Results

The resulting coefficients and parameters are given in the table below along with the r squared value and Theil's U statistic. To compare the accuracy of the model and of the validation test, Theils's U has been calculated for the results derived from the modelling and from all the results combined after validation, thus being U1 and U2 respectively. The formulae used is given below:

$$U = \frac{\sqrt{\frac{\sum_{t=1}^{n} e_t^2}{n}}}{\sqrt{\frac{\sum_{t=1}^{n} F_t^2}{n}} + \sqrt{\frac{\sum_{t=1}^{n} x_t^2}{n}}} \tag{9}$$

Where F = predicted cost, x = actual cost, n = sample size and e = x - F

Table 2: Coefficients and statistical results of modelling and validation

Model	**R square**	constant	**A1**	**A2**	**B1**	**B2**	**U1**	**U2**
1	0.82101	0.74779	0.7167		0.25262		0.104	0.142
2	0.82194	-0.12024			0.28565	0.13037	0.116	0.782
3	0.82151	0.55079			0.28666	0.24845	0.113	0.149
4	0.82179	0.9160			0.13208	0.71089	0.106	0.619
5	0.82189	1.7247	1.7321		0.17778	0.24788	0.112	0.147
6	0.82365	2.0608	1.1587	4.2277	0.50748	0.00022	0.115	0.148

The following graphs show the relationship between the actual energy cost and predicted energy cost for all models produced in the paper, not including the validation stage.

Fig. 4. reafirms the information provided in the results Theil's U coefficient in that the curve of actual cost is close to that of predicted cost. However, in order to qualify the data, a validation test was carried out using the four sports centres that were not used during modelling. Inserting the independent variables into the models, predicted total energy costs were derived and then assessed for accuracy using Theil's coefficient. It was discovered that models 2 and 4 have a Theil's coefficient of more than 0.5 as shown in Table 1. Hence, these two models are not good predictor of energy consumption costs. The other four models however returned a U statistic pro-rata to that calculated for U1. Upon inspection, Model 1, which relates the variables in a linear fashion, was found to be most accurate.

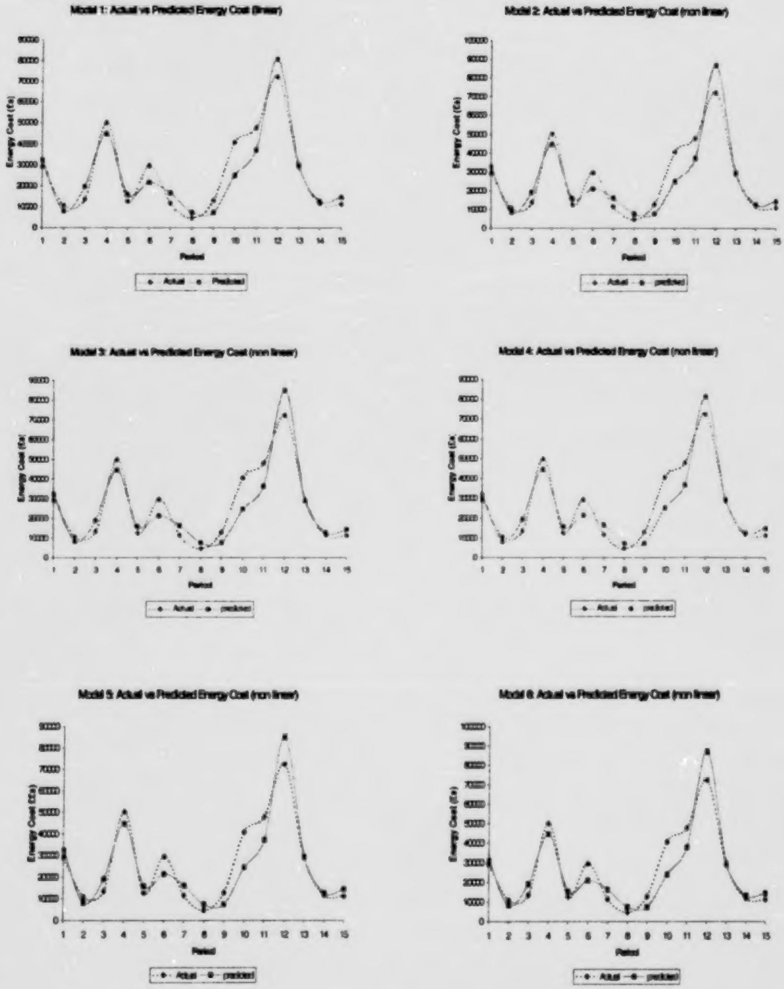


Fig. 4 Comparison between actual and predicted cost

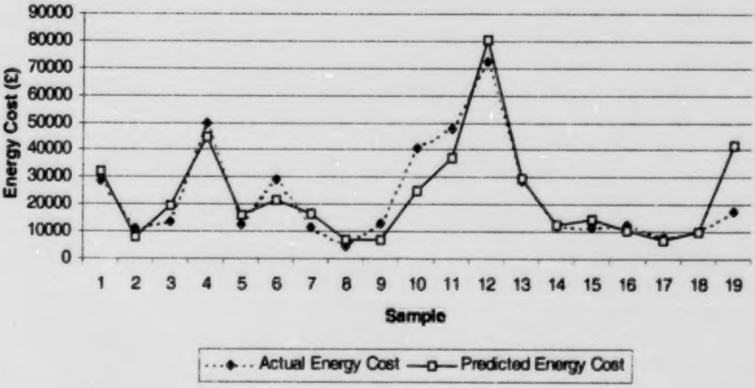


Fig. 5 Example of testing and validating- Linear Model 1

7 Discussion

The results show a strong linear relationship between the variables and in some cases, a non linear relationship as well. The accuracy of the predicted energy costs is favourable but one has to this, there are many factors outside the scope of the model which will have an impact upon forecasted values if used in other studies. Many of these factors have been highlighted earlier in the paper, and can be attributed to noise in data. The use of modelling in predicting energy costs should be used not only in the context described here but also as a tool for reducing future energy consumption in sports centres. Again the principle variable which is difficult to quantify is user inference. Occupants and facilities mangers need to be made aware how their actions can in the long term have a significant impact on energy costs.

8 Conclusion

This paper presented an initial investigation into the prediction of energy running costs of leisure centres. The approach incorporated the notion that the running cost depends on several energy consumption influencing factors. In this paper two main factors (area, and number of users) were used to develop six linear and non-linear models. Testing and validation show that the energy consumption is best fitted to linear model. These type of models can be used at an early stage of the design process to carry out what-if scenarios.

9 References

Ashworth, A. (1985) Cost Models, Their History, Development and Appraisal, CIOB Technical Service, Paper 64

Ashworth, A. (1994) Cost Studies of Buildings, Longman Scientific, Second edition

Audit Commission, The (1988) Saving energy in local government buildings, HMSO

Bowen, P.A. and Edwards, P.J (1985) Cost Modelling and Price Forecasting: Practice and Theory in Perspective, E & FN Spon

Brandon, P.S. (1992) Building Cost Research – Need for a Paradigm Shift from Building Cost Techniques – New Directions, E & FN Spon

Burt, M.E. (1978) A survey of Quality and Value in Building, Building Research Establishment

Dixon, B.R. et. al. (1987) A Handbook of Social Science Research, Oxford University Press

Energy Efficiency Office, (undated) Best practice for design of sports centres

Fellows, R. and Liu, A. (1997) Research Methods for Construction, Blackwell, Oxford.

Ferry, D.J. and Brandon, P.S. (1991) Cost Studies of Buildings, BSP Professional

Flanagan, R. and Norman, G. (1983) Life Cycle Costing for Construction, RICS, Surveyors Publications

Flannagan, R. et.al. (1989) Life Cycle Costing, Theory and Practice, BSP Professional

Fortune, C. (1998) A Price on design, Research Paper Series, RICS

Fortune, C. and Lees, M. (1996) The relative performance of new and traditional cost models in strategic advice to clients, Research Paper Series, RICS

Holmes, R. (1994) CIOB Handbook of Facilities Management, Edited by Alan Spedding, Longman

Leifer, D. (1997) A Basis for the Economic Appraisal of Intelligent Building Proposals, Proceedings of IB/IC Intelligent Buildings Congress, Tel-Aviv, Israel

Newton, S. (1991) An Agenda for Cost Modelling Research, Construction Management and Economics, E &FN Spon

Robson, C. (1993) Real world research, Blackwell, Oxford

Seeley, I.H. (1985) Building Economics, McMillan

Skitmore, M. (1991) Early Stage Construction price Forecasting – A Review of performance, Occasional Paper, RICS

164 STONE CLEANING: A LIFE CYCLE COST MODEL

R.A. Laing, A. Al-Hajj, J. Ball, J. Scott, and M.E. Young

The Robert Gordon University, Aberdeen, UK

Abstract

The application of stone cleaning methods can result in damage to a stone surface, in addition to any visual changes. The physical condition of the stone following cleaning can degrade over time, leading to an increased repair and maintenance requirement. The effects of cleaning are most obvious immediately following the application of cleaning methods. When soiling is removed, an often lighter and more appealing stone colour will be uncovered, leading with certain stone types to a likely increase in the attractiveness of a building. Stone degradation may not become obvious until some time afterwards, concealing any link between cleaning and decay and making a link seem doubtful. Stone cleaning, if seen rightly as being the beginning of a long term alteration, carries with it a range of costs and benefits, in both the short and long term. It is essential that the life cycle effects of cleaning are considered prior to cleaning works, and a life cycle cost model provides a powerful and useful tool for the decision maker. The incidence of maintenance and repair work depends on both the rate of decay and the practice of those responsible for payment. Using data provided from a mapping of the effects of cleaning on a range of buildings, the rates of stone decay attributable to cleaning will be established. The likely frequency of work completed due to this decay has been established through contact with experts and practitioners. Areas of uncertainty will be included in the model through use of the Monte Carlo technique. The resulting cost model will be useful through the provision of a unique "value" in relation to the life cycle effects of cleaning, and indications of where benefits or costs may change due to evolving attitudes toward cleaning.

Keywords: financial, life cycle cost, stone cleaning, stone decay.

Durability of Building Materials and Components 8 (Volume Three). *Edited by M.A. Lacasse and D.J. Vanier*. Published in 1999 by NRC Research Press, Ottawa ON K1A 0R6, Canada. ISBN 0-660-17742-0

1 Introduction

Many buildings in Scotland have been cleaned over the last two to three decades, although the effects of such cleaning have begun to be fully understood only recently. The reasons for the continuing popularity of cleaning include the perceived improvements in visual quality and possible financial gains. Due to the known potential for damage to the stone itself, though, there is a counter balance which must be considered. This paper describes a project concerned with attempting to develop a model of the financial life cycle resulting from that balance, allowing in the future for the prediction of financial effect prior to cleaning.

2 Approach

A life cycle cost model was structured conceptually in accordance with accepted practice, allowing the project team to identify those variables for which the current data set was deficient. Previous work (Newby et al. 1991) attempted to model the future potential for the stone cleaning market, based on the likely incidence of re-cleaning, with no mention of the potential for damage to the stone. Research published since that work (Andrew et al. 1994, Webster et al. 1992) has shown conclusively that the actual financial situation presents a combination of potential costs (financial cost of repair work) and benefits (aesthetic benefits leading to possible increases in property market values), and this is reflected in the cost model developed here.

Life cycle costing techniques are based on the premise that total value is equal to the present value of initial and future cash flows (Johnson et al. 1987). Note that past costs are not considered, and that the model assumes only costs and benefits realised from cleaning onwards will be of interest. This is represented by Bromilow et al. (1987) through the following expression:

$$\mathbf{S_T = C_0 + C_{it} + C_{jt} - d} \qquad \mathbf{(1)}$$

where,

$\mathbf{S_T}$ is the present discounted life cycle cost measured over a period T
$\mathbf{C_0}$ is the total cost of procurement at time zero
$\mathbf{C_{it}}$ is the annual cost, which may be regarded as continuous
$\mathbf{C_{jt}}$ is the cost of non - continuous work, which will not happen on an annual basis
$\mathbf{d}$ is the value of an asset on disposal (taking account of the costs of that disposal)

This equation relates closely with the discussion so far, in that the equation allows for each of the constituent variables in the financial value system to be included. The inclusion of variable **d** allows for any possible gains to be included in the model. Variable C_0 refers to costs and benefits at the time of cleaning. Table 1 indicates the variables which are to be considered, as well as the variable heading under which each is categorised.

Table 1: Variables for life cycle cost model

Variable	Cost elements relating to this project
C_0	• testing at pre-cleaning stage • initial cost of cleaning • re-pointing required at cleaning stage • treatment at cleaning stage
C_{it}	• regular re-pointing
C_{jt}	• stone repair • re-cleaning (including testing)
d	• changes in market value of building • reduction in stone repair incidence

The final variable, "reduction in stone repair incidence", has been cited to reflect arguments for the continued cleaning of stone buildings. The belief is that cleaning can uncover certain defects in the stone previously "hidden" by a soiling layer, prompting repair work at an earlier stage than would otherwise be the case. Where this were true, it is possible that a reduction in overall stone repair cost would be realised. This argument is flawed, however, in that soiling of a stone surface rarely if at all masks defects in the stone where the observer is experienced and trained with regard to building surveys[1]. It is possible, however, that if an experienced observer were not present that cleaning might well result in decay becoming obvious, and thus prompt the application of repair work. The variable has, therefore, been included in the model outline, but in reality would be likely to have little impact. With regard to changes in market value, the percentage indicators reported in Laing and Urquhart (1997) will be applied[2]. The data requirement of this investigation is shown in Table 2.

In the longer term, the potential exists for cleaning to lead to increased levels and rates of decay (Urquhart et al. 1993). The financial cost of work associated with this relates to the extent of decay, the point at which decay becomes intolerable, the likely intervals at which repair work will be implemented and the costs of work and materials specified.

The extent of stone decay resulting from cleaning is being investigated through the mapping of over 200 sandstone buildings in Scotland (see Young et al. 1999). The results of that exercise will identify the range of possible decay effects which can result from cleaning, and provide the financial model with likely frequency distributions. Such decay will only carry a financial cost where it is deemed necessary that work is completed to rectify or halt the decay process.

The variables in Table 2 relate to interventions resulting from decay, as opposed to the decay itself. Cost data relating to the work was gathered through contact with parties responsible for the specification of repair work and stone masonry firms, including data concerning the labour, plant and materials requirement. The costs included in the model are limited to considering the cost of completing work, and exclude wider environmental costs and benefits (such as those concerned with material sources).

---

[1] On limestone buildings, it is possible that thick black crusts built up on the stone surface could lead to stone decay becoming obscured. This project relates to sandstone buildings only, however, and that set of circumstances does not apply.

[2] The likely percentage increase in property market selling or letting prices was investigated in Laing and Urquhart (1997). The indicators vary depending upon building use and location.

Table 2: Data required for incorporation in the life cycle cost model

Variable	
Initial cost of cleaning	• cost of cleaning/m^2 for a representative sample of cleaning methods[3]
	• cost of temporary works (both apportioned with other works, and solely with cleaning)
	• cost of testing
	• specialist surveys and reports
	• linked to method of cleaning
Re-pointing (initial)	• cost of re-pointing
	• influence of listed building regulations
Re-pointing (regular)	• extent (for modelling purposes)
	• projected cost
	• anticipated rate of incidence
	• linked to method of cleaning
	• influence of listed building regulations
Stone repair	• initial condition of stone pre-cleaning
	• size of facade
	• stone carving present
	• stone type (e.g. sandstone or granite)
	• linked to method of cleaning
	• cost of repair work
	• consultancy costs
	• influence of listed building regulations
Re-cleaning	• anticipated rate of incidence
	• costs involved
	• influence of listed building regulations
	• possible link with initial method of cleaning
Alteration in market value	• building use
	• location
Reduction in repair incidence	• Please refer to note below Table 1.

3 Discount rate

For all but the initial costs, it is necessary to discount the costs to calculate values at the base year. The outcome of any life cycle cost model is highly sensitive to the discount rate selected. The discount rate is used to simulate the influences of interest rates and inflation over time, making the reliability of the model's outcome highly dependant on the chosen discount rate being accurate. Over time, however, it is obvious that interest rates will vary, meaning that a discount rate must properly reflect these long term changes, and represent a realistic average. To help ensure that the model reflects the range of possible outcomes, a risk analysis and a methodology to be followed in practice is presented as part of the model itself (making use of the Monte Carlo simulation approach and a sensitivity analysis). Although the model's outcome will exist over a range of possibilities (presented with a frequency distribution), that range will more accurately reflect the likely outcome than a mean value with standard deviation.

---

[3] Although generic costs have been used here, measured in m^2, costs would in reality be influenced by an on- site assessment by the works estimator.

In addition, data regarding the resource implications is being sourced through a survey of stone masons (see Section 5). The possibility of extensive repair works seeming less important due to time elapsing between cleaning and decay cannot be ignored, so intervention works will be presented as both a financial cost and resource cost (i.e. labour, materials and plant).

4 Specifier survey

A survey of specifiers (selected Architects experienced with heritage properties) has gathered information regarding building maintenance programmes, stone cleaning, stone repair and maintenance (intervention) and materials sourcing for repair purposes. Data was required as to the work which could be expected as a result of decay uncovered by the mapping exercise, the point at which such work would be completed and the costs of such work. Information concerning the specification of work was gathered, uncovering both the motivations behind repair work and the work itself. Wherever possible, specifiers were selected with regard to their previous involvement in the maintenance and repair of buildings of historical importance, as it was felt that a "best practice" approach might be reflected in the responses. It was felt also that the specifier's role is to offer expert advice to the Client, thus helping ensure that a "best practice" approach is actually followed.

From the perspective of modelling the costs of intervention, the most important questions concerned the point at which, and for what reasons, stone repair work would be undertaken. The respondent group was asked to state whether or not they believed stone repair to a building facade would be required due to a range of factors (these factors linking with variables in the mapping project). The results are shown in Table 3.

Table 3: Reasons for stone repair

Possible reason	**Repair?**		
	Yes (%)	**No (%)**	**Unsure (%)**
Natural weathering and mineral movement	80	10	10
Bleaching/ staining from cleaning	20	65	15
Surface decay	55	30	15
Delamination	80	10	10
Insensitive redressing	70	20	10
Insensitive/ decayed plastic repair	90	0	10
Face bedding of stone	60	30	10

Subsequent questions asked respondents to *quantify* the point at which the above variables would require work (i.e. % of the facade affected). The responses to that question reflected the fact that each building is in a unique set of circumstances, and subjective criteria were offered. Nonetheless, the results shown in Table 3, linked with those criteria and results forthcoming from the mapping exercise, will provide useful predictive frequencies for work following cleaning. Therefore, where a building is being considered for cleaning, it will be possible to predict (within a distributed range) the extent of decay and subsequent repair work which would emanate from that cleaning.

All respondents to this survey indicated that they would avoid the specification of stone cleaning work, due to their awareness of the dangers posed to the stone itself. A great deal of cleaning has been completed to date, the effects of that cleaning mapped as part of this project. If the respondent group here can be taken as representative of Architects throughout Scotland, it would seem that rates of cleaning in the future will decline.

5 Stone mason survey

A series of surveys is ongoing with stone masons working in the field of stone repair and replacement. The aims of this study are to uncover the costs of stone repair (as specified by the respondents in the previous study), and give further indication of the criteria important to the selection of materials.

This study will also lead into further work considering the cost implications of matching stone for repair purposes. The number of quarries operating in Scotland is today much less than was the case 100 years ago. The implications for sourcing stone for repair purposes are potentially far reaching, as the specifier survey indicated that 85% of respondents had considered or undertaken a return to the original source. The results also indicated a lack of agreement as to the costs or resources of such work, and that a clarification was required.

6 Discussion

The unique and valuable nature of this project stems from the close links between the mapping exercise (reported in Young *et al*, this volume), and the cost study. Long term work, associated with stone cleaning, is required due to accelerated decay mechanisms leading to a desire (or need) for a making good of that decay. Unlike many life cycle costing studies, where natural obsolescence would lead to a similarly natural need for replacement, the repair work being investigated here could be avoided were stone cleaning not carried out.

The mapping exercise has been undertaken to highlight cases, and the circumstances, in which stone cleaning has led to increased levels or rates of decay. Data from that exercise will be fed into the life cycle model, allowing pre-cleaning predictions of likely decay, repair requirement and overall financial cost (or benefit) to be included as part of the decision making process.

Aesthetic benefits resulting from stone cleaning must be regarded in many cases as transient, due to inevitable re-soiling. Where a financial loss is predicted over the long term, many building owners and specifers might be likely to avoid stone cleaning, making the implications of this project for the stone cleaning industry great.

7 Conclusions

This paper has described work ongoing, due for completion during 1999. The strong links between the physical mapping and the life cycle cost study in themselves present a useful and original contribution to knowledge. The final model will facilitate better informed decisions, and avoid unnecessary damage to buildings.

8 Acknowledgements

This research was commissioned by Historic Scotland.

9 References

Andrew, C.A., Young, M.E. and Tonge, K.H. (1994) *Stonecleaning: A Guide for Practitioners*. Historic Scotland and The Robert Gordon University. ISBN 0748008748.

Bromilow, F.J. and Pawsey, M.R. (1987) Life Cycle Costs for University Buildings, *Construction Management and Economics*, Vol. 5, Part SI, pp. S3-S22.

Johnson, K.E., Sherif, A. and Becker, F.D. (1987) Economics of University Research Laboratories, *Construction Management and Economics*, Vol. 5, Part SI, pp. S31-S42.

Laing, R.A. and Urquhart, D.C.M. (1997) Stone cleaning and its effect on property market selling price. *Journal of Property Research*, Vol. 14, pp. 329-336.

Newby, P.T., Mansfield, T.A. and Hamilton, R. (1991) Sources and Economic Implications of Building Soiling in Urban Areas. *The Science of the Total Environment*, Vol. 100, pp. 347-365.

Urquhart, D.C.M., MacDonald J., B Thomson.W., Tonge, K.H. and Young, M.E.(1993) Stonecleaning in Scotland. A Cause for Concern?, in *Management, Maintenance & Modernisation of Buildings*; Proc. of International Symposium, Vol. 6, CIB Working Commission 70, Rotterdam.

Webster, R., Andrew, C.A., MacDonald, J., Thomson, B., Tonge, K., Urquhart, D.C.M. and Young, M.E. (1991) *Stonecleaning in Scotland, Research Report*. Volumes 1-3, Report to Historic Scotland and Scottish Enterprise by Masonry Conservation Research Group, Gilcomston Litho, Aberdeen.

Young, M.E., Ball, J. and Laing, R.A. (1999) Effects of stonecleaning on decay rates of building sandstones, in *8th International Conference on Durability of Building Materials and Components*, Institute for Research in Construction, Vancouver, Canada.

165 CONDITION SURVEY OF TORONTO'S HIGHRISE RENTAL STOCK

S.J. Marshall[1] and G. Genge[2]

[1]Canada Mortgage and Housing Corporation, Ottawa, and [2]Genge Building Consultants Inc., Sutton West, Canada

Abstract

In 1995, Toronto City Council requested assistance from CMHC in the development of a strategy to ensure the proper maintenance and conservation of highrise rental housing. The task was to clarify the actual physical condition of this building stock and to determine the capital costs expected to maintain them over ten years. A building condition survey was carried out to determine repair costs for 10% of the total rental building stock for rental buildings in Toronto and York, over 5 stories in height. The buildings were grouped according to age: pre-1960s, 1960s, 1970s and post-1970s. The audit evaluated all major residential building systems, including site, garages, balconies, structure, walls, roofs, windows and doors, all mechanical systems, as well as emergency systems. It was found that the average cost of repair predicted for the 63 buildings was approximately $7,500 over ten years, with pre-60s buildings averaging $9,000, and post-70s buildings averaging $1,980. The costs were grouped into time periods in which the work would become necessary. The average figures indicated that approximately 33% of repairs would be required in six to ten years and 38% in three to five years. The rest of the costs should be incurred within two years. The major items in terms of future costs were power distribution, elevators, windows and garages, whereas windows, garages and balconies were found to require the largest expenditures in a two year time span.

Keywords: building systems, repair costs, building audits, residential building, capital costs

Durability of Building Materials and Components 8 (Volume Three). *Edited by M.A. Lacasse and D.J. Vanier*. Published in 1999 by NRC Research Press, Ottawa ON K1A 0R6, Canada. ISBN 0-660-17742-0

1 Introduction

This survey was initiated to determine the state of repair of multiunit highrise rental properties in the Toronto area and to establish the costs required to extend their longevity. A prior Apartment Conservation Study in 1992 by Hemson et al identified emerging issues of an aging and deteriorating stock, some acute problems in bringing this stock up to good condition and several buildings too costly to repair. Seventy-seven percent of apartments in Toronto are 20 years or older.

One objective of the present study was to generate a cost-effective assessment methodology which could be applied in future to other regions as well. CMHC's interest is also to develop a better understanding of the condition of existing highrise buildings in order to determine what more cost-effective repair methods are needed, and to identify potential research priorities. The sponsors also want to use the results to promote long-term conservation of the housing stock by working with landlords and tenants.

The survey protocol, developed by Gerald R. Genge Building Consultants Inc., was carried out by building auditors selected because of their extensive experience. The auditors evaluated the conditions and the ten-year repair costs of the selected residential rental properties. The sample was selected randomly to represent the highrise housing stock of central Toronto. The 63 properties reviewed represented approximately 10% of the sample building universe of the old cities of Toronto and York. It included social housing and private rental properties. Building owners and managers participated voluntarily, encouraged by the Fair Rental Policy Organization of Ontario. Owners who participated in the survey received a free building audit as an incentive.

2 Methodology

The inspection protocol and terms of reference of the audit work were developed in the first phase of the project. During the second phase, the potential property pool from which the buildings were to be randomly chosen was developed. The buildings eliminated were those that were less than 5 stories, mixed use or condominiums, dormitories, nursing homes or constructed prior to 1930. The study attempted to select the buildings by vintage according to their approximate frequency in the sample universe. The age groupings were pre-60s, 1960s, 1970's and post-70's to give a total of 63 buildings out of a universe of 546 buildings. The sample selected 27% social and 73% private rental stock. Ten out of eleven post 70s buildings were of social housing stock.

Table 1: Building Sample

Age Grouping	Number of Buildings	% of Sample
Pre-sixties (30s to 50s)	16	25
1960s	28	44
1970s	8	13
Post-seventies	11	18
Total	63	100

During the course of 1997, the 63 buildings were assessed under seven physical parameters (divided into twenty-one subsystems) which include:

1. Site
2. Building Structure
3. Building Envelope
4. Mechanical
5. Electrical
6. Life Safety
7. Elevators

For each parameter, the cost of building repair or replacement was determined for the next 10 years, on a per-unit basis. (See Fig.1) A rating was assigned for each building to express its condition in terms of repair urgency and safety/usability. Costing methodology (most cost-effective repair) and sampling procedures were also elaborated and pre tested.

Buildings were also analyzed according to the time frame of repair needs: immediate, 1 to 2 years, 3 to 5 years and 6 to 10 years. The usefulness of the data was somewhat lessened with regard to the impact of previous maintenance by the lack of information available as to previous repair work undertaken. The auditors had to rely on their experience and knowledge of the systems to evaluate these aspects. The samples did not show significant differences between social housing and privately-owned rental stock. Histograms of the data, although not presented in this paper, were developed for both costs of repair and for the rating of all the systems assessed.

3 Results

The survey indicated that the average cost/unit for repairs over ten years was $7,474 for all work, excluding regular maintenance items such as interior finishes. There was significant variation from this average,from highest repair-cost building at $21,258/unit, to the lowest at $124/unit. Given this variation, the average unit cost can be misleading. Quartile data is a more useful way of evaluating the range of costs. Complaints were issues raised by tenants and maintenance staff. (Table 2)

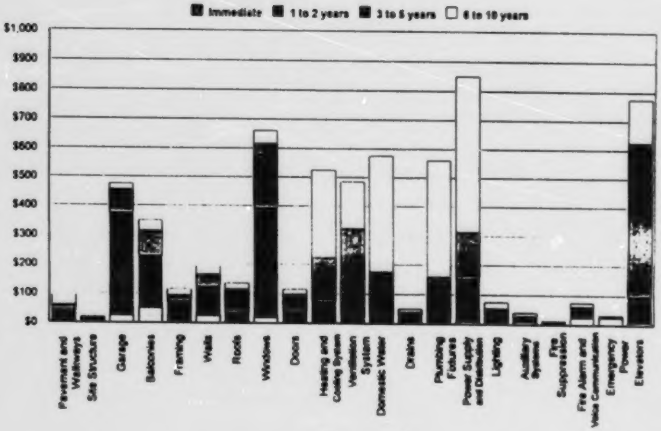


Fig. 1:Ten year repair costs by time frame and component

3.1 Structural Systems

- Garages, balconies and framing remain issues which have not been fully addressed by owners.
- 60s and 70s buildings represent the greatest costs, averaging $531/unit. Of particular concern is the absence of protective membranes on garage floors for 40-50% of these buildings. These resulted in complaints about leakage, high repair and waterproofing costs.
- 60s buildings also have high balcony concrete repairs, in which carbonation makes their repair a priority. 75% of their repair costs were below $678/unit.

3.2 Building envelopes

- The survey results show that the costs of envelope repairs were high, a total of 19% of the total costs over the next 10 years.
- The highest envelope related costs are for pre-60s buildings.
- Most of the envelope expenses for all building vintages were required within one to two years, except for post-seventies buildings which have immediate needs.
- Sixties buildings were in urgent need for window and balcony door repairs.
- The high complaint rate due to leaks in post-70s buildings should be cause for concern for building designers and builders. Complaints due to leaks in exterior walls rose from 12% in pre-sixties buildings to a high 45% in post-seventies construction.

Table 2: Complaint rates due to leaks

Age Grouping	Window Leaks	Wall Leaks
Pre-sixties	12%	12%
1960s	25%	32%
1970s	50%	25%
Post-seventies	36%	45%

The study shows the evolution of wall design in Toronto, which is mostly brick masonry, from the early solid masonry before the sixties to the brick veneer with 4" concrete or steel stud backup used today.

- Cavity walls with 1" spaces began to be used in the sixties, when 10% of the construction used this design.
- In the 70s, 60% of buildings had 1" to 1.5" wide cavities. Average wall insulation has increased from R3.1 prior to 1960 to R9.1 after 1980. However, cavity insulation was found in only 13% of the 70s and 27% of the post-70s.
- The higher repair costs and ratings in the 80s and 90s buildings suggest that these buildings are not as good as earlier work. Improper design principles or faulty construction may be factors. More caulking is used to resolve details. Only 18% of post-seventies construction employed air barriers. The audits indicated that airtight air barrier construction was infrequent for all vintages, in spite of research2 indicating the importance of this aspect of construction.

3.3 Windows

Windows are high cost repair items. (See Fig.2) The low complaint rate of 60s buildings (see Table 3) compared to later construction may be accounted for by the fact that 50% of the windows from the 60s, and 75% of windows from earlier buildings, have already been replaced. 8% more have had window perimeters recaulked. None of the 70s buildings of the sample have replaced windows yet.

The considerable cost of window repair and replacement for 60s buildings is a major expense, close to $1000/unit. The 70s windows will also need replacement after a life of 25 to 30 years, based on the data obtained. Designers should consider and evaluate another window design parameter, the ease of window replacement. Windows selected for durability, thermal resistance and window assemblies capable of being built with air barrier continuity are important assets for property owners. They provide a more comfortable environment for occupants. But even more, the farsighted selection of window assemblies which provide for the ease of window replacement (with its associated reduced costs) would be a considerable asset to property owners. As windows become due for replacement, owners have the option of installing more [2]Drysdale et al, *Exterior Wall Construction in High-Rise Buildings*, CMHC, Ottawa, 1992 thermally-efficient units which are now more commonly available. At this time serious consideration should be given to these better windows, because of the important potential savings in mechanical systems, which could be down-sized at the time of replacement.

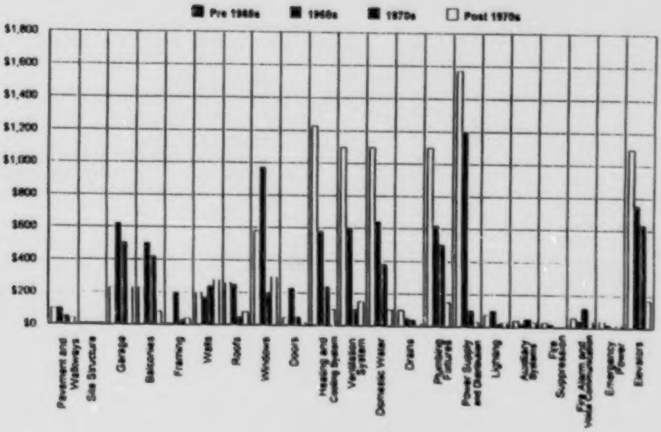


Fig. 2: Comparison of unit costs by subsystem and age group

3.4 Roofs

Inverted Roof Membrane Assemblies predominate in 1970s construction. However, repairs for roofs of built-up materials continue to use the original system. It appears that IRMA repair requirements are lower due to the protection of the inverted membrane.

3.5 Mechanical systems

Mechanical systems are the highest cost repairs required in the 3 to 10 year period, especially in the pre-60s buildings. Complaints of lack of heat, control of temperature and poorly working valves were noted. Ventilation system complaints concerned humidity, corridor make-up air adequacy, and insulation. Complaints about plumbing and water supply concerned leaks, weak pressure, and valves not sealing.

- Heating repairs typically involved boiler and pipe replacement in pre-60s at a 75th quartile cost of $2.742/unit. The average age of pre-60s boilers was 26 years, showing that some were long overdue for replacement.
- Make-up air in pre-60s buildings costs less than $2,526/unit for 75% of the units. Almost half of pre-60s buildings have no corridor pressurization, accounting for humidity and odour problems.
- Plumbing and domestic water repairs average about $2,300/unit, for the pre-60s.

3.6 Electrical systems

Power supply and distribution, lighting and auxiliary systems have high cost in the 6 to 10 year term, highest for the pre-60s buildings. Complaints about over fusing of panels with no additional capacity were common. These buildings need general upgrades at a 75th quartile cost of $2,917/unit.

3.7 Elevators

Elevators are high-cost and high-maintenance systems. Their average cost/unit is relatively high, $780 being 12% of the total ten-year repair costs for all buildings. Elevators' life span is related to use, abuse, safety and accessibility upgrades. Equipment changes are principally due to age and the availability of replacement parts, as well as safety upgrades. Discussions with some property managers indicated that if replacement parts were available for older systems, many of them would be kept in service over a much longer period. Hoists required the most costly repairs.

- Pre-60s construction, averaging 7 stories in height, required only one elevator car in half the buildings. 60s apartment buildings increased to an average of eleven stories, resulting in over half these buildings requiring three or more elevators. These 60s projects need most of the work to be done within one to five years.
- 70s buildings averaged eleven stories, with 50% having 2 elevators and 38% having three.
- Post 70s buildings expect elevator work in six to ten years.

- 60s apartment buildings increased to an average of eleven stories, resulting in over half these buildings requiring three or more elevators. These 60s projects need most of the work to be done within one to five years.
- 70s buildings averaged eleven stories, with 50% having 2 elevators and 38% having three.
- Post 70s buildings expect elevator work in six to ten years.

3.8 Tenure

A cross section of ownership type was considered, but insufficient data was retrieved to make a useful distinction between single-building owners and multiple-building owners or between public and private housing owners.

- Average ownership tenure of property was greater than ten years, showing a high stability.
- Building managers tenure tended to be more volatile, with only about one quarter with the same building more than ten years.
- At the level of superintendence, the majority, 58%, remain 5 years or less.

This may explain why knowledge of previous work on the properties is lacking. On-site records were often unavailable and there is no continuity in the maintenance and records of buildings. To better maintain the building stock, more effort is required to keep accurate logs of repair work projected and completed. If a superintendent has records of what repairs were done, the costs, and their durability, he is in a far better position to consider more cost-effective repair strategies.

3.9 Exceptional costs

Seven buildings showed exceptionally high costs. The highest cost per unit was $21,258 over ten years. Five of these buildings are pre-sixties buildings with 40 units or less. These buildings must have the cost of repairs spread among fewer units, which could be a heavy burden for the owners and occupants. The highest percentage of repair costs estimated for these high cost buildings were related to mechanical, envelope, electrical and structural systems. In all but two of the buildings, the mechanical system repairs account for the highest percentage of the costs. The mechanical repairs included new exhaust air systems, replacement of plumbing fixtures, boiler replacement, radiators and cold water galvanized supply pipes which no longer function adequately.

Eight buildings had total costs per unit of less than $2,000 over ten years; all but one of these buildings were constructed in the 1980s and 1990s. Several post-70s buildings also had repair costs which were close to the average of $7,500.

3.10 Energy conservation measures

Only one response was received from the energy savings survey, although it was observed that energy efficient lighting had been installed in about 80% of the buildings. Very few changes have been made to other systems, possibly due to slow payback or recovery disincentives. These improvements include garage and exterior lighting redesign, garage exhaust controls, dryer conversion to natural gas, domestic hot water and boiler control replacement. Weather-stripping in windows was not carried out unless new windows were installed. Tenant awareness programs are in place in approximately one quarter of 1960 and post-1970 buildings.

3.11 Ratings vs. Costs

Costs did not always describe the condition of the building. Repair costs can be high for items which do not have a high rating (such as window replacement), or costs can be low for items with a high rating (such as repair of isolated spalled brick). Ratings were determined by the auditors based on priorities of repair: time, safety and usability. The ratings record can be used for future comparison purposes to determine if the building population, systems or building has worsened or improved.

4 Summary

- The three major subsystems requiring the largest investment are the electrical power supply and distribution, the elevators and the windows. All these systems, as well as mechanical systems in general, are major expenses for buildings built prior to the seventies. From the point of view of urgency, windows and garages have the greatest repair need within two years (see Figure 3). Mechanical and electrical systems are the priority costs in the three to ten year periods. Elevators costs will peak in three to five years. Most life safety repairs have already been done, since these are the object of regulatory controls.
- Over the next ten years from the time of the survey, the pre-60s buildings have the highest per unit costs: under $5,500/unit for 25% to under roughly

$17,000/unit for 75% of the buildings. Several 1930s buildings need substantial work, with a maximum cost of $21,000/unit..

- 70s buildings have similar typology to sixties buildings, and so can expect similar repair costs in the future. Over ten years, the repair cost range is under $2,500/unit for 25% of the units, under $4,500 for 75% of the units, with a maximum cost of $6,000/unit.
- Most of the post-70s buildings in the sample are social housing. Over ten years, the costs range from under $500/unit to roughly $3,500/unit for 25% and 75% of the buildings, respectively. Maximum cost is estimated at $7,000/unit over ten years for post-seventies buildings.

In the future, should the data of this study be extended to other areas, the typology of the systems - design and construction - must be confirmed as similar to those of the study. The data should not be extended across age groups since age is a primary trigger for repair.

Several initiatives are suggested as a result of the information gathered in this condition survey. These include:

- Evaluation of the impacts of these future costs on owners' capital planning. It would be important to investigate the exceptional buildings with a high repair cost burden in particular.
- The evaluation protocol and assessment parameters could be used as guides for smaller owners wanting to plan future expenditures. Results for other buildings can be compared using the rating system which was developed.
- Best practice case studies would show the advantage of using consistent maintenance worksheets and capital planning in maintaining rental property. Several mechanical and electrical maintenance and repair guides are in preparation for owners and managers.
- The report also shows that the technical problems of window construction, selection, repair and replacement also need to be clarified for owners, managers, design professionals and builders. Elevators, another high cost system, could also receive similar consideration. Cost-effective and durable solutions for the design and repair of these systems would provide the basis for further Best Practice Case Studies.
- Garage and balcony repairs also remain a concern in seventies and even in post-seventies buildings. Best practice in their design and maintenance should be promoted.

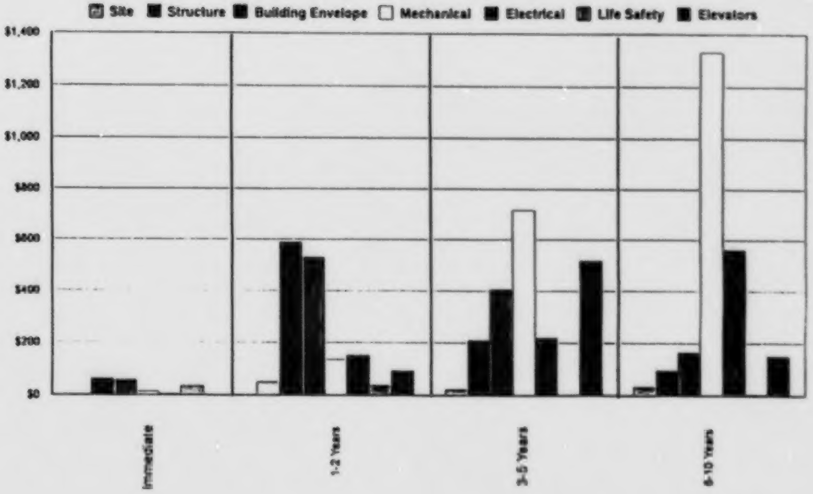


Fig. 3: Comparison of unit costs, all buildings, by subsystem and time frame

5 References

Drysdale, R.D., Suter, G.T. (1991) *Exterior Wall Construction in High-Rise* Buildings. Canada Mortgage and Housing Corporation, Ottawa

Hemson Consulting, Morrison Hershfield Limited and Fraser & Beatty (1992) *Apartment Conservation Study*, for the City of Toronto

166 DETERMINING THE IMPACT OF QUALITY UPON LIFE CYCLE COSTS

L.A. Newton and A.J. Christian

University of New Brunswick, Fredericton, NB, Canada

Abstract

Defining and quantifying the impact of quality in design and construction upon facility life cycle costs is increasingly relevant as organisations strive to deal with Canada's infrastructure deficit. In construction, a "quality building" could mean one in which highly durable materials were used; it could mean a facility in which craftsmanship is outstanding or it could simply mean a facility in which the design and construction process is ISO 9000 compliant. Current meanings of quality in construction were examined for their applicability and a new method for determining quality costs using a "quality quotient" is proposed. A research programme has been developed, in co-operation with the Department of National Defence (DND), to objectively determine the impact of quality upon life cycle costs. Using data gathered from detailed study of five categories of common DND facilities, it will be possible to determine life cycle costs for each facility and compare deviations to determine the degree of quality in each. This research will enable facility and asset managers within DND to forecast costs associated with each component of life cycle management and best determine where to focus 'quality control/assurance" and "quality management" efforts for the greatest return on life cycle costs.

Keywords: quality, construction, life cycle costs, facility management, ISO 9000, asset management

Durability of Building Materials and Components 8 (Volume Three). *Edited by M.A. Lacasse and D.J. Vanier*. Published in 1999 by NRC Research Press, Ottawa ON K1A 0R6, Canada. ISBN 0-660-17742-0

1 Introduction

Defining and quantifying the impact of quality in design and construction upon facility life cycle costs has become increasingly relevant as organisations strive to deal with Canada's infrastructure deficit. Research to date has found that while it is logical to assume inferior quality of design, workmanship or materials will impact upon future operation and maintenance costs, the extent to which this will increase costs can not be readily ascertained. This problem arises for two significant reasons: (1) the meaning of quality and (2) lack of historical cost data. Firstly, the definition of quality means different things to different people, that is, it can be performance based, "needs" based or defined in terms of conformance. In construction, a "quality building" could mean one in which highly durable materials were used; it could mean a facility in which craftsmanship is outstanding or it could simply mean a facility in which the design and construction process is ISO 9000 compliant.

Even if a common meaning of quality were used, past research endeavours have been impeded by the lack of historical cost data and commonality in both design and in the operation and maintenance (O&M) of facilities. Thus, the impact of quality upon life cycle costs has been determined subjectively with life cycle costs being based on projections or estimations of how a facility will perform using the performance expectations of individual components, eg, roofing. In order to determine the impact of quality upon life cycle costs, the aforementioned problem must be solved.

2 Life cycle costing

Life cycle costing involves the determination of all costs associated with the pre-design, design, construction, O&M, rehabilitation and reconstruction or demolition of civil works. Invariably a structure lasts longer than the original owner, designer and contractor who were involved with the facility. Thus, the most recent owner is left with O&M costs which according to Christian and Chan (1993) can be up to 85% of the total life cycle costs when combined with interest costs. Previous work (ASCE, 1988) on quality in construction showed that the greatest influence on life cycle costs occurs during the design phase and declines throughout the construction phase until there is little influence upon reaching the O&M phase. Hence, the costs currently faced by the owner or facility manager were set long before he or she became involved with the facility.

The pre-design phase begins with a statement of requirement by the owner in which the following key questions regarding life cycle costs should have been considered:

- What is its function?/What is the need?
- What is the anticipated lifespan of the infrastructure?
- What is the required lifespan of the facility?
- Will it become redundant in some capacity before the end of its useful lifespan?
- Are major rehabilitations predicted, and at what frequency?
- Who will the user(s) be?
- What are the proposed budgets for design, construction and O&M?

The design is based on the answers to these fundamental questions. As an example, it is not economically practical to design a building to last 50 years if the owner only wants it to last 20 years before demolishing it.

For a facility manager to be able to forecast O&M expenditures and budget effectively there must be a means of predicting what impact quality has had on the life cycle costs of the facility. Without precise data to present a case for maintaining O&M funding at or greater than existing levels, the facility manager finds that an O&M budget is a prime target for cost cutting as organisations strive to deal with deficit reduction. This is compounded by the fact that the relatively long life span of most infrastructure is such that the user or owner is not necessarily aware of the severity of degradation until major rehabilitation is required. For example, the New Brunswick Department of Transportation (NBDoT) summer road maintenance funding declined in excess of 30% in current year dollars (1993$) over a 30 year period from 1965 - 1995 (Newton, 1997). Today the NBDoT is faced with the requirement to rehabilitate most major routes and in one case, has turned to a public-private partnership to finance the construction and upgrading of the TransCanada highway from Fredericton to Moncton.

3 The meaning of quality

"Quality" became the mantra of day in manufacturing in the 1980's and has now taken on equal significance in construction. Yet, this one word has many different meanings. Table 1 summarises the results of a comprehensive review of the concept of quality. As can be seen, quality has traditionally been defined either subjectively in terms of "excellence" or "performance" or objectively in terms of "conformance".

Table 1: Quality concepts

Definition	**Nature**	**Proponent**
conformance to requirements	objective	ASCE (1988) BS 4778 Davis et al (1989) Ashford (1989) ISO 9001
performance to meet the needs of user or customer	subjective	Christian & Chan (1993) Todorov (1996)
degree of goodness or excellence	subjective	Freund (1985) Oxford Dictionary (1992)

Differentiating the meaning of quality in this manner leads to conflicting perspectives when trying to determine the impact of quality upon life cycle costs. A user may have different requirements than an owner or may not realise that what he considers "poorer" quality components, such as wooden windows, actually does meet the owners requirement for a low cost, short term building. Whose perspective is most important, the user, the designer, the owner or facility manager? Arditi and Gunaydin (1998) found that there was strong agreement between design professionals, constructors, property (facility) managers and construction managers in ranking factors that affect quality in their respective involvement in the phases of the life cycle of building projects. Their work however, did not consider the user. In the context of total quality, performance and conformance are not mutually exclusive. Rather, they are inter-related as shown in figure1.

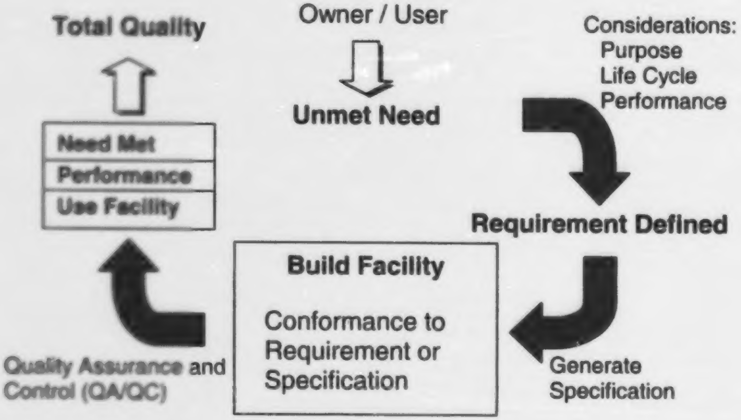

Total Quality
Owner / User
Considerations:
Purpose
Life Cycle
Performance
Unmet Need
Need Met
Performance
Use Facility
Requirement Defined
Build Facility
Conformance to Requirement or Specification
Quality Assurance and Control (QA/QC)
Generate Specification

Fig. 1: Relationship between performance and conformance

McGeorge and Palmer (1997) propose that quality is not defined through isolated perspectives but, is a combination of the following:

- manufacturing based - conformance to requirements or a specification
- product based - based on a specific measure or characteristic such as durability
- user based - extent to which the user is satisfied
- value based - what is the "best buy"

This diversification in turn leads to an objective list of "principal quality dimensions". Accepting that the meaning of quality is not one dimensional removes the constraint of perspective imposed when quality is evaluated based on one definition or another. The "dimensions" proposed by McGeorge and Palmer are: performance, reliability, conformance, durability, serviceability, aesthetics and perceived quality.

4 Quality and life cycle costs

Using this broad meaning of quality , the question that must now be addressed is how can quality costs and their impact on life cycle costs be determined? The four most common methods, based on ISO 9004-1, are:

1. Fiegenbaum's quality costing method.
2. Crosby and Philips' process costing method which examines the costs of conformance and non-conformance.
3. Taguchi and Genichi's quality loss method which is founded on a loss function model.
4. PAF (prevention, appraisal, failure) method which associates costs with each activity and allocated those costs according to the categories of prevention, appraisal or failure.

The problem with using the above methods in infrastructure life cycle costing is twofold. Firstly, they are strictly based on "conformance". While quality related activities can be tracked during design and construction to provide a quality cost for these two phases, the models are too detailed to be of use in a general prediction of the impact of quality on O&M costs. Secondly, they can not be used to evaluate the quality costs associated with older infrastructure. Accordingly, a new method has been proposed that determines quality costs based on a "Quality Quotient".

4.1 The quality quotient

The "quality quotient" method (QQM) of determining the impact of quality upon life cycle costs is based on the relationship between the life cycle of infrastructure and McGeorge and Palmer's quality dimensions. Three options exist for the intended life of infrastructure. They are:

- Long Term (50+ years): no anticipated change in use, periodical rehabilitation, reconstruction or demolition at end of life cycle
- Mid-term (25-50 years): potential change in use, mid-life rehabilitation, potential to extend life span through reconstruction, demolition at end of life cycle
- Short Term: (< 25 years): no change in use, demolition at end of life cycle

It is recognised that depending upon the purpose and projected life span of a facility, the relative importance of the dimensions will vary. A preliminary ranking of the importance of the factors to the intended life of the infrastructure is suggested in table 2. It should be noted that this does not take into account the perspective of those associated with the design, build and O&M of the facility. As this is considered to be significant, a questionnaire is being developed that will ask owners, facility managers, designers, constructors and users from both the public and private sector to rank and weight the importance of the factors for the life cycles.

Table 2: Ranking facility life and quality factors

Quality Factor	Long Term	Ranking Mid-term	Short Term
performance	3	3	6
reliability	2	1	4
conformance to requirements	5	5	2
durability	1	2	7
serviceability	4	4	3
perception	7	7	5
aesthetics	6	6	1

4.1.1 Developing the quality quotient.

The objective of the QQM is to quantitatively determine the impact of quality upon life cycle costs. This will assist facility and asset managers in predicting life cycle costs and enable them to determine where to focus quality assurance (QA), quality control (QC) and management efforts for the greatest return on life cycle costs. The next question is how can the quality quotient or QQ be calculated? Options include the development of a weighted equation or a decision matrix that will take into account the variables proposed in table 2 and generate a QQ value for a given facility. It is suggested that the QQ value fall within a determined range such that when considered in conjunction with known life cycle costs it will be possible to determine the degree of quality in the facility and to quantify the impact that it will have on future costs. It will also be possible to apply the QQ to new facilities to predict future O&M costs.

A simplified, hypothetical example of how the QQ value and pre-determined life cycle costs might be used to calculate the impact on future life cycle costs is shown in table 3. What remains to be addressed is how the QQ will deviate depending upon the quality factors. If an equation is used, how do we determine weighting factors for the variables? If a decision matrix is used, do the factors inter-relate and how can they be quantified to provide a numerical output?

Table 3: Hypothetical example of impact of quality upon life cycle costs (LCC)

QQ	Impact Upon Costs	Calculated LCC ($/m^2/year)	Predicted LCC ($/m^2/year)
8-10	No variation upon LCC	$100	$100
6-8	+ 10% change in LCC	$100	$110
4-6	+ 25% change in LCC	$100	$125
2-4	+ 40% change in LCC	$100	$140
0-2	> 50% change in LCC	$100	> $150

5 Research programme

A three year research programme, has been developed in co-operation with DND. The proposed programme entails studying five categories of buildings: accommodations, aircraft hangars, drill halls, kitchens and office accommodations, at nine military bases in Eastern Canada. These facilities range in age from 40 years to newly constructed and, within their respective categories, share a commonality in design. It is therefore, possible to determine life cycle costs for each facility and compare deviations to determine the impact of quality in each. Using historical construction and O&M cost data, a database will be built that will determine life cycle costs for each facility. The database will then be used in conjunction with the QQ to determine the impact of quality upon life cycle costs.

5.1 Lack of historical data

As mentioned previously, the greatest impediment to past research endeavours has been the lack of historical cost data and commonality in the approach to the operation and maintenance (O&M) of facilities. The Department of National Defence (DND) is an ideal source of data for the following reasons:

- there is commonality in design and construction
- there are well defined facility O&M procedures
- recorded historical cost data exists for the entire life of all facilities

Initial research at the Combat Training Centre (CTC) Gagetown was undertaken in the Fall of 1997 to see if sufficient data was available to pursue in-depth research. The results were promising and life cycle costs were determined for nineteen barrack blocks. As a result of this initial success, DND was approached for permission to expand the research to other bases as detailed above.

5.2 CTC Gagetown: A preliminary case study

A preliminary attempt was made to determine the impact of quality upon life cycle costs using the facility data obtained at CTC Gagetown. Three categories of barrack blocks or accommodation facilities, were examined and life cycle costs were calculated based on historical O&M costs. Common features of the buildings included the same designer, identical age and life expectancy and similar standards of maintenance. Building design was consistent within categories but varied between categories. A summary of the findings for those buildings that had not undergone mid-life rehabilitation is shown at table 4.

Table 4: Barrack block life cycle costs (LCC)

Bldg Type	Intended Life	LCC ($/m^2)	Interior Maintenance Costs ($/m^2)	Basic Construction
250-man barracks	50 years	$2530	$21.60	RC foundation, walls, floors and roof deck
senior ranks quarters	50 years	$2830	$43.80	RC foundation, CB walls, concrete floors and roof deck
officers quarters	50 years	$2885	$33.50	RC foundation, CB walls, concrete floors and pitched roof on wood deck

RC: reinforced concrete CB: concrete block

An analysis of average life cycle costs indicated that the costs were approximately 10% less for the 250-man barrack block. If interior maintenance costs only were considered, the difference was even more significant. In an attempt to account for this finding, building specific construction, in particular interior finishes, was examined in greater depth and compared with the intended use, ie., the occupant. The 250-man barrack block is of reinforced concrete construction with 3/4" plastered walls, terrazzo tile flooring in the halls and mastic tile in the rooms. Washroom and shower facilities consist of two common areas per floor. It was built to standards that would ensure maximum performance and durability thereby allowing it to withstand the constant turnover and lack of attention that is typically seen in a facility with transient personnel. Applying the quality factors from table 2, it can be seen that this facility was constructed with a quality ranking comparable to that of a long term facility. This "over-design" accounts for the significantly lower interior maintenance costs. The other two categories of barracks were built to house more senior personnel and were thus, constructed on a smaller scale (maximum 48 occupants) with greater attention being paid to how the user would perceive the building. The concrete block construction is again plastered but the floors are asphalt tile. While common washroom and shower areas are found in both structures, the officers' quarters have individual sinks in each room. Although maintenance and LCC values are higher for those buildings that have undergone mid-life rehabilitation, these general findings are also applicable.

5.3 Future research

Collection of data for the four other categories of facilities is now underway at CTC Gagetown. The data will be entered into a database that is being developed to determine life cycle costs. Once life cycle costs are known, the quality factor ranking and resulting quality quotient will be determined. This methodology will then be applied to the eight other DND establishments to further define and quantify the impact of quality upon the life cycle costs.

6 Conclusions

Research to date has indicated the potential to quantify the impact of quality in design and construction upon facility life cycle costs given historical cost data and commonality in design, construction and O&M. By describing quality in terms of several dimensions rather than a single meaning, the perspective of the designer, constructor, owner/facility manager and user can be incorporated to yield a quality quotient. The relationship between the QQ and known life cycle costs will allow for the determination of the degree of quality in a facility and the impact that quality will have on future O&M costs.

7 References

American Society for Civil Engineers. (1988) *Quality in the Constructed Project. A Guideline for Owners, Designers and Constructors, Vol. 1.* ASCE, New York.

Arditi, D. and Gunaydin, H. M. (1998) Factors That Affect Process Quality in the Life Cycle of Building Projects. *Journal of Construction Engineering and Management*, Vol. 118, No. 1, pp.35-49.

Ashford, J. C. (1989) *The Management of Quality In Construction.* E & FN Spon, London.

British Standards Institution. (1987) *Quality Vocabulary, Part 1, International Terms.* BSI, London. BS4778.

Christian, A.J. and Chan, Y. (1993) Quality Management in Facilities Management. *Canadian Society for Civil Engineering Annual Conference Proceedings.* Vol. 3. pp. 223-232.

Davis, K., Ledbetter, W. B. And Burati, J. L. (1989) Measuring Design and Construction Quality Costs. *Journal of Construction Engineering and Management*, Vol. 115, No. 3, pp.385-400.

Freund, R. A. (1985) Definitions and Basic Quality Concepts. *Journal of Quality Technology.* Vol. 17, No. 1. pp. 51-56.

McGeorge, D. And Palmer, A. (1997) *Construction Management New Directions.* Blackwell Science Ltd., Oxford.

Newton, L.A. (1997) *A Study of Maintenance Management Practices and Expenditures on New Brunswick Roadways.* Master's Thesis. University of New Brunswick.

The Oxford Dictionary of Current English. Second Edition. (1992) (ed. D. Thompson), Oxford University Press, Oxford.

Todorov, B. (1996) *ISO 9000 Required.* Productivity Press, Portland.

167 ACCRUED VALUE ASSESSMENT — A DYNAMIC APPROACH FOR INVESTMENT APPRAISAL AND FACILITIES MANAGEMENT

T. Plenty, S.E. Chen, and W.D. McGeorge

University of Newcastle, Callaghan, Australia

Abstract

Construction projects typically involve a variety of decision-makers that decide on alternatives that generate capital and on-going costs during a project's life. These capital costs generate value for different stakeholders and potential for returns to the project owner, which are durable and vary over the life cycle of the completed project. Conventional investment appraisal techniques, which focus on cash flows represented by the costs and expected returns of a project discounted to a common base period, do not reflect the total value of capital expenditure choices which include intangible and non-monetary benefits as well as reduction of future costs and financial returns. This paper discusses an approach in which project decision-makers evaluate and allocate identifiable value from capital and continuing costs to relevant stakeholders and periods in the life cycle of the project. The objectives of different stakeholders for the project can be taken into account in the assessment of project expenditure value. The ability of a project owner to recover a premium for identified accrued value will provide incentives for up-front spending where the potential for improving overall project performance is greatest. Discounting procedures will allow the value of the project to be appraised at any stage of the project's life cycle. This approach leads to a technique, which is more refined than conventional appraisal of earning potential with the ability of a project owner to recover a premium for identified accrued value. The accrued value assessment also provides a useful tool for facilities management and design decision evaluation. The approach builds on and is embodied in a larger framework for project decision support, which aims to improve overall project performance.

Keywords: Accrued Value Assessment, Facilities Management, Decision Support.

Durability of Building Materials and Components 8 (Volume Three). *Edited by M.A. Lacasse and D.J. Vanier*. Published in 1999 by NRC Research Press, Ottawa ON K1A 0R6, Canada. ISBN 0-660-17742-0

1 Introduction

It is not desirable in terms of a life cycle perspective for initial and continuing capital costs to be minimised, if the future financial performance of the project is disproportionately penalised. However, as different stakeholders come into play over the project life cycle, there is a natural propensity for developers to trade off their initial capital costs against costs that might be incurred by future stakeholders.

Hence rational capital cost decisions cannot be decided unless the value of these up-front costs can be identified and factored into the investment appraisal of the project at any period in its life cycle. These costs would be recovered from other stakeholders who would benefit from the enhanced financial performance of the project. This would provide the incentive for the developer to invest additional value up-front and improve the life cycle costs associated with the project for subsequent stakeholders.

It is also desirable for the developer and subsequent stakeholders to monitor the continuously changing status of an investment and use the data to assist decision making in subsequent projects or benchmark between alternative projects. One method of accomplishing this is to take into account the accrued (time dependent) value of capital decisions and allowing this to be factored into the investment decision.

This paper proposes the use of an integrated decision approach that identifies values up-front, together with continuing capital costs and accrues these to the appropriate period in the project life cycle.

The concept has merit for a number of stakeholders in the project life cycle. In addition to the incentive offered by the ability of a project owner to recover a premium for identified accrued value, subsequent purchasers (investors) are given an accurate 'real value' assessment of a project at any stage in the project life cycle. Current methods of investment appraisal fail to identify the 'real' initial value injected into the project and do not discriminate with respect to future capital costs to be incurred once alternative stakeholders are introduced.

This paper will provide an overview of current investment appraisal techniques and investigates the relative merits of each tool. The accrued value assessment concept is introduced and a review of the advantages it offers is undertaken. Finally the paper outlines an implementation strategy that maps the concept through the design production, construction and facilities management stages of the project life cycle.

2 Current methods of investment appraisal

The conventional investment appraisal and facilities management techniques currently available are briefly outlined below. Two distinct types of methods currently exist. The first type does no take into account the timing of cash flow. The general approach adopted by these various methods centres on cash flows represented by the costs and expected returns of a project. These methods include: accounting rate of return, investment yield and pay back period. The second type however does take into account the timing of the cash flow discounted to a common base period. The methods that fall into the second include:

Net present value (NPV) - return on investment

Net present value is the simplest and most commonly used discounted cash flow method for capital investment appraisal consists of calculating the value in the present year of all the cash flows associated with the project, and then adding these values together. This results in the total being known as the net present value (NPV) of a project (Dixon, 1994).

Internal rate of return (IRR)

The IRR represents the rate of return on capital expended that the owner would obtain for the initial investment in the project (Ferry & Brandon, 1991). The IRR is the interest rate, which results in the capital outlay being paid off by the incoming cash flows at the end of the life cycle of the project, after deduction of 'interest payments' for capital outstanding.

Life cycle costing of individual building elements

Life cycle costing is a method of evaluating all of the relevant costs associated with a project throughout its life. In a construction project the analysis is usually performed with respect to construction, maintenance, running and demolition costs. However life cycle cost analysis can be adversely effected by inflation and the limited nature of a one off life cycle costing analysis tends to limit the reliability of an extensive study into the main building cost items (Sierra, 1999).

3 Advantages and disadvantages of current techniques

The alternative investment appraisal techniques outlined previously provide the basis by which property investors decide to invest, hold or divest of a capital works project. Significant use is made of these techniques at project initiation and throughout the design development and documentation period to firm predictions of project worth.

Figure 1 indicates the stage of the project life cycle in which current approaches to investment appraisal finish, i.e. at design documentation. Each method is completed at this stage with nothing following through to aid in investment decision making during the construction stage or post project completion. This has significant implications for changes in scope during and post completion, which should be factored into the decision to invest. Indeed the ability to update and compare the initial study post project completion is very difficult and sometimes not possible.

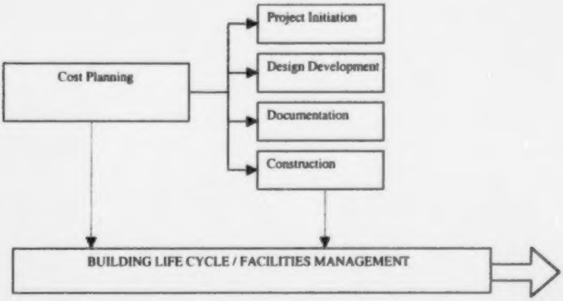


Fig. 1: Investment Appraisal and the project life cycle

As widely applied as the current methods have been they do not reflect the total value of capital expenditure choices, that includes intangible and non-monetary benefits as well as the reduction of future costs and financial returns. In addition all current approaches to investment appraisal fail to consider the evolution of the continuously evolving facilities management concept and the extensive list of the implications this has for property ownership.

The majority of the current techniques were developed prior to the evolution of current facilities management concepts. The changes in the property investment environment, which have included property syndication, the proliferation of property trusts, outsourcing of non core facilities management functions and significant taxation changes (with respect to the Australian context) all require a tool to evaluate individual property returns on an ongoing basis.

Facilities management provides the property owner with an integrated management system focused on the efficient management and control of a property or whole portfolio. The link between property and the core business objectives of an organisation is the key concept within the evolving facilities management discipline.

The evolution and change in facilities management has effectively changed the investment appraisal focus to require emphasis on the continuing value of holding every individual property. This value will change over time as the building ages, taxation benefits are reduced and the cost of maintenance and other recurrent capital expenditure increases. Hence there is the need for a tool that can provide an ongoing decision aid for investment appraisal and facilities management.

4 Accrued value assessment: a dynamic approach to investment appraisal

This paper describes a new approach to track the value of an investment over its entire life cycle. As outlined previously, current methods of investment appraisal focus on project initiation and fail to adequately keep pace with the changing nature of project once completed. This new approach provides different stakeholders in the project life cycle with a tool that can also be used to manage the financial planning, both capital and recurrent, of the project. Once the initial assessment has been completed the same document will evolve of the life of the project to be used by successive stakeholders who may enter post project completion.

4.1 The Accrued value concept

The accrued value assessment tool can be extended beyond maintenance planning and costing to include other ongoing expenditure that is continually attributable to the life cycle of a completed building. Examples may include, land tax, rates, essential services and condition audits, asset registers, taxation changes and benefits associated with ongoing capital works, leasing fees, insurance's, year 2000 compliance expenses and a host of other items.

The general concept is graphically shown in Figure 2, below. This diagram illustrates the extended scope of the accrued value concept. The line A-A delineates the base for dissecting the accrued value profile of the building three years post completion. Not only are the capital costs expressed in annual terms, but also each asset management cost can be assessed individually to reflect the changing nature of management costs over the entire building life cycle. This aspect will be particularly important for stakeholders who enter post completion and require information in order to manage the facility and anticipated associated costs.

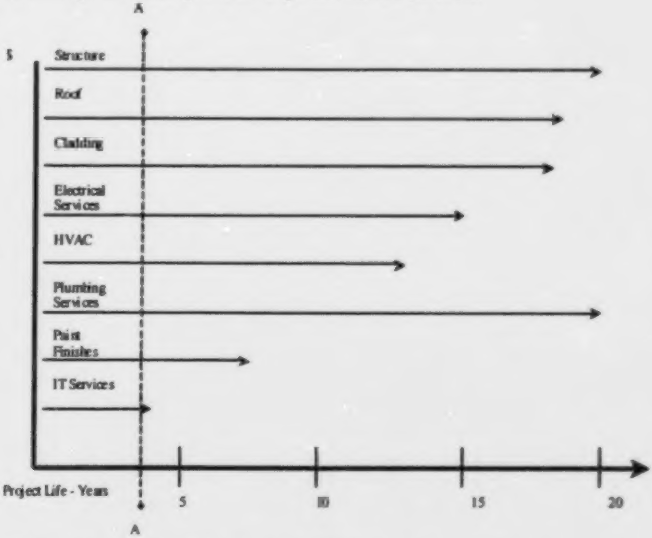


Fig. 2: Accrued value profile of initial construction

Accrued value assessment is intended to provide a whole of life initiative for decision support in all stages of the project life cycle. The technique offers the ability to evaluate 'dead' and 'live' items of a building and the ability to track their condition over the period of the buildings life cycle. A unique aspect of the tool is the ability to make an investment decision based on the actual historical evidence that has been accumulated since the building was completed. This data would incorporate the original decisions made on building plant and equipment and the reasons for their selection.

Particular advantages offered through the application of the technique are envisaged to include:

1. A tool to determine where major project costs have been incurred.
2. As a method of determining the value of an individual investment past, present and future.
3. The ability to project and track the future fluctuations in value over an extended period of time. This will enable an investor or purchaser to base decisions on more concrete data and generate significant information from which the value of individual property investments can be benchmarked on a real return basis.
4. Provide the maximum continuous taxation advantages from all items of plant and associated equipment.
5. The ability to forecast major cost items years ahead.
6. The potential to be applied at due diligence stage to benefit both the vendor and the purchaser.
7. Appraise, on a continuous basis, the accrued value of an individual building or a large portfolio.

One of the most significant advantages outlined above is the ability for project decision-makers to evaluate and allocate identifiable value from capital and continuing costs to relevant stakeholders and periods in the life cycle of the project. This provides an objective basis for valuing a property asset for balance sheet purposes.

The tool offers the added benefit of flexibility in data entry so as complex calculations including such aspects as the changes in taxation aspects and emergency equipment replacement can be tracked and their total effect on asset value determined. The ability of a project owner to recover a premium for identified accrued value will provide incentives for up-front spending where the potential for improving overall project performance is greatest.

The accrued value assessment also provides a useful tool for facilities management and design decision evaluation. It offers the facility manager a comprehensive financial package, these can be used to set performance targets and benchmark existing and new projects. Specific problems or issues can be tracked and action taken well ahead of issues arising. The ability of the building to adapt to technology and the changes associated with such can be assessed and costs for essential upgrading,. For example, year 2000 compliance, can be projected.

Design decision support is provided with a financial data collection tool that can track individual buildings and provide evidence for all stakeholders to improve performance.

4.2 Implementation strategy

The ability to implement the concept from project initiation through the design production, construction and facilities management stages of the project life cycle is not only essential in order to maximise the value of the concept as a decision support tool but also crucial.

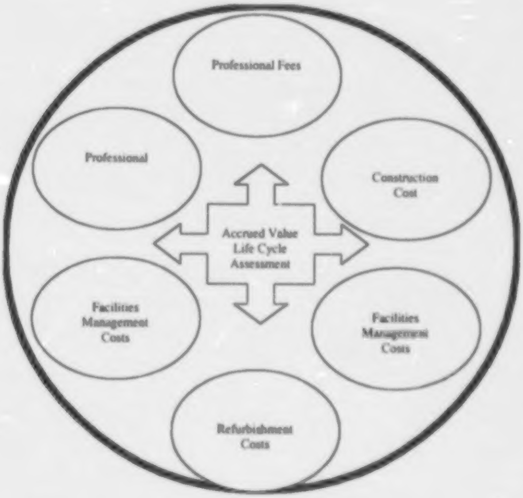

Professional Fees
Professional
Construction Cost
Accrued Value Life Cycle Assessment
Facilities Management Costs
Facilities Management Costs
Refurbishment Costs

Fig. 3: Scope of data required for implementation

The tool has the potential to pass from one stakeholder to another a fair and true value of major building costs that will aid in the determination of overall project value and return on investment. It is envisaged an implementation strategy would require the building owner to invest significantly more in cost advice and facilities planning at project initiation. From this foundation the ability to control and apply the data to the completed project is at its highest.

5 Conclusion

The assertion that the construction industry lacks any real incentives for up-front spending where the potential for improving overall project performance is greatest has been stated repeatedly. Accrued Value Assessment is intended to provide a whole of life perspective for all stakeholders in order to maximise the investment worth of spending funds in the initial stages prior to construction. The benefits of such can then be realised by subsequent stakeholder reward. If value is made explicit then it is more likely be recovered by appropriate premiums paid when the property is passed from one owner to another.

The consistent practice of Accrued Value Assessment from initial cost planning to on-going facilities management would greatly improve the life cycle management of any physical asset and add to best practice performance principles within the construction industry.

6 References

Dixon, R. (1994) *Investment Appraisal, A Guide for Managers*, The Chartered Institute of Management Accountants, Kogan Page, London,UK.

Ferry, D. & Brandon, P. (1991) *Cost Planning of Buildings*, BSP Professional Books, Oxford, UK.

New South Wales, Public Works Department, Policy Division. (1999) *Total Asset Management Manual*, New South Wales Government, Sydney, Australia.

NPWC (1989) *Life Cycle Costing*, Australian Government Publishing Service, Canberra, Australia.

Robinson, J. (1989) *Property Valuation and Investment Analysis: A Cash Flow Approach*. The Law Book Company, Melbourne, Australia.

Sierra, J. (1999) *Basic Building Economics*, The Australian Institute of Quantity Surveyors, Canberra

Smith, J. (1998) *Building Cost Planning for the Design Team*. Deakin University Press, Geelong, Australia.

168 REAL ESTATE RENOVATION DECISIONS BASED ON COST APPROACH APPRAISING PRINCIPLES

I. Pšunder

University of Maribor, Slovenia

Abstract

In the real estate life-cycle we often encounter a problem regarding decision of renewal of the building or selling it and replacing it with similar one of equivalent utility. This decision is usually based on a deficient calculation. It considers the market value of property only, compared with its depreciated book value. The intention of this research was to quantify all variables which occur in the real estate life-cycle. The method applied is based on the theory of real estate appraising and adopted for usage for building and investment purposes. Besides the market value, physical depreciation, as well as functional and economic obsolescence of the real estate, are considered. The method gives adequate results which are often of great assistance while trying to solve the problem of renewal or selling of the real estate. This technique is a firm basis for the decision-making process of the mentioned problem.

Keywords: appraising, life-cycle, real estate, reconstruction, replacement

1 Introduction

It is commonly known that real estate value changes with time, but contrary to popular belief it is not necessary that the value always decreases. Experiences have shown that value of hypothetically un-obsolesced real estate (such real estate where obsolescence hypothetically does not increase with time) even increases in the longer period. Real estate is namely basis of the urban functioning of society. Therefore, with increased social and economic activities in the society, a demand for real estate in urban centers increases, and, consequently, prices of real estate also rise. The lack of spare space results in rise of prices of land. A hypothetically un-obsolesced building or its part is nowadays more expensive as a few years ago. In some cases this is true even for buildings despite clearly visible signs of physical depreciation or obsolescence.

Durability of Building Materials and Components 8 (Volume Three). *Edited by M.A. Lacasse and D.J. Vanier.* Published in 1999 by NRC Research Press, Ottawa ON K1A 0R6, Canada. ISBN 0-660-17742-0

The reason is that ruling prices depend on long-term increased demand for spare space in urban centers.

But if we have in mind a building or its part which is maintained averagely and we subtract abrupt market oscillation caused by under- or oversupply then it is obvious that - despite of long-term capital growth of the real estate investment - value of the building depreciates. Why?

Firstly, the building physically depreciates with time because of atmosphere and environment aggression. As physical depreciation we consider an adverse effect on the value caused by deterioration of condition. Physical depreciation can usually be reduced or abolished by renovation of the building. Money equivalent of the physical depreciation can be calculated and defined on the basis of invoices, catalogues, tenders, contracts, etc. By definition of size of depreciation we are seeking for an answer to the question: "How much do we have to invest to abolish physical depreciation and to reset the conditions equal to a new building?"

Secondly, buildings tend to functional obsolescence. This is a lack of utility of the building caused by inadequate or obsolete design, structure or material. Lessening of utility has adverse influences on the value of the building. Functional obsolescence either can or cannot be abolished. In other words functional obsolescence may be curable or incurable. If we cope with curable obsolescence we can determine the equivalent sum by answering this question: "How much should we invest to reach state-of-the-art standards in design and structure?"

Finally, by appraising the building value we cope with economic obsolescence, caused by adverse influences outside the building. Usually, economic obsolescence is incurable which means that in most cases buildings cannot be corrected or a correction is not economically feasible.

2 Value and price of a building

We can now estimate value of a real estate property by estimating reproduction or replacement costs and by deducting the loss in value caused by physical deterioration, functional deficiencies, and economic obsolescence. Estimation of reproduction cost is in fact a calculation of the costs needed for the production of an exact replica of the subject building or property. Replacement costs estimation is based on the calculation of the costs of producing a building or a property with equal utility to that of the subject one. The procedure is based on the collection of invoices, catalogue prices etc. While deducting the depreciation of the value from the reproduction or replacement value, we get the estimated value of the property calculated by the usage of the cost approach.

The value of the property can also be estimated by using the income approach. The idea of a income approach is that the value of the property depends on income that the subject property can potentially produce. The most accurate income approach method takes into account future stream of incomes or net cash flows received from the property. To get the value of the property, either net income or net cash flow, it has to be divided by an appropriate capitalization rate. The best way to collect data - potential gross income or potential cash inflow, and an appropriate capitalization rate - is to deduct them from market analysis.

A kind of income approaches are also rules-of-thumb techniques of real estate appraising. By using rules-of-thumb techniques we apprise the value of the property by multiplying potential income or cash flow with particular multiplier. These techniques are easy to understand and use. Therefore, they are often used when several income properties should be apprised in a short period of time. Data used by rules-of-thumb techniques are collected by market analysis.

An additional possibility of appraising an income property is to estimate its value by using a market comparison approach. By using this method an appraiser estimates the value of the property by comparing it to similar properties that were recently sold. By considering the disparities between comparable properties and the subject one can deduct the estimated market value of the apprised property.

All methods mentioned above give an estimated value of the building or property but fails to automatically tell us the price of the property. The price is the negotiated amount of money which is actually paid for the property.

In the real word, despite taking into consideration all market disparity, there are differences between estimated value and the actual price (Fig. 1). The reasons for this are interpreted below.

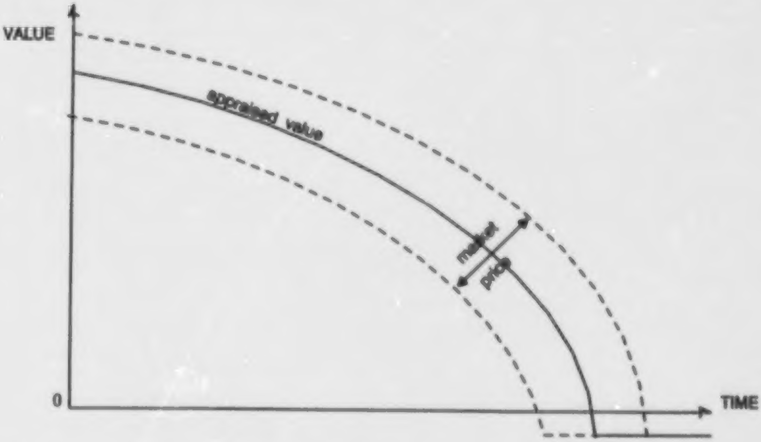


Fig. 1: The deviation of market price from the apprised value

3 Investment decisions

Decision making in civil engineering and property management are (at least in Central and Eastern European countries) usually not made using the property appraising theory but simply based on real estate accountancy. That means the investors calculate depreciated book value of the real estate (purchase cost of the real estate reduced by the book depreciation) and compare it with the market value of the real estate. Basically, this approach is not wrong but it almost always lacks accuracy and is therefore inadequate for investment purposes. The supposition that

$$PC - BD = MP, \quad (1)$$

where
PC = purchase cost,
BD = book depreciation, and
MP = market price,
is superficial (if not even wrong). It namely results in the following. If

$$PC - BD > MP \quad (2)$$

then it is, according to the equation, reasonable to renew the building. If one would sell it one would receive less money that the book value of the property. With the money we would receive from the selling we could not afford an equivalent substitute building. (Logically, this statement can also be used in the opposite case, if PC - BD < MP.)

This decision is supported by the equation and logically correct. Where is the mistake? The book depreciation cannot adequately describe a real condition of the building. Therefore, by using this methodology, we make a hidden mistake. Even by a correct calculation, this decision is not right because calculation is based on wrong suppositions.

4 Solution of the problem

The solution is found in the use of real estate appraising in investment decisions. Implicating earlier mentioned statements in the equation (1) we get a new equation as follows:

$$PC - PD - FO - EO = MP, \quad (3)$$

where
PD = physical depreciation,
FO = functional obsolescence, and
EO = economic obsolescence.

In the equation (3) all types of depreciation and obsolescence are considered, therefore, it can be used in the well-developed real estate market without limitations.

Occasionally, market value of a building oscillate from the theoretical suppositions. In such cases the equation can be used as a help while making investment decisions as follows. If

$$PC - PD - FO - EO < MP, \quad (4)$$

then the reconstruction of a building is economically not reasonable. The cost of abolition of depreciation and obsolescence would exceed the cost of purchasing a non-depreciated and non-obsolete building with equal utility.

Why is then a potential buyer prepared to overpay for a property? Because price of property is, above all, a matter of market liquidity. For example, a residential property loan, which in Slovenia is periodically offered to young families, in a short term increases the market price of residential apartments.

An opposite case is when an oversupply is present. In that case

$$PV - PD - FO - EO > MP. \tag{5}$$

The equation reflects present oversupply, therefore, depreciated value exceeds market price. Such situation occur when, due to an excessive erection of buildings or due to an oversupply caused by bankruptcy or liquidation of enterprises, lower the market price of real estates. In such cases, it is not economically reasonable to sell the subject building or a part of it. It is reasonable either to renew the building or, in case of selling it, to wait for more appropriate market conditions.

5 Conclusion and summary

Enterprises which deal with real property investment, maintenance and rehabilitation should, by their decisions, consider all types of depreciation and obsolescence. Investment calculations based only on book depreciation of a building lack relevant data of depreciation expanse and are therefore not suitable for investment purposes.

It is much more appropriate to implement real estate appraising principles with an investment calculation. This approach gives a very clear description of building condition and is therefore very helpful in making decisions whether to renew or sell the building depending on the circumstances on the market. The only problem which still persists in this approach is difficulty of an adequate quantification of functional and economic obsolescence expanse.

6 References

Airey G.J. (1998) *The property investor's handbook*, Wrightbooks Pty Ltd, Elsterwick.

Friedman J.P., Ordway, N. (1989) *Income Property Appraisal and Analysis*, Prentice Hall, New Jersey.

Jaffe A.J., Sirmans, C.F. (1995) *Fundamentals of Real Estate Investment*, Prentice Hall, New Jersey.

Pšunder I. (1997) Sodobne metode vrednotenja nepremičnin (State-of-the-art methods of real-estate valuation), *Nepremičnine*, Maribor (in Slovene).

169 CONSIDERATION OF ENVIRONMENTAL ISSUES WHEN RENEWING FACILITIES AND INFRASTRUCTURE

S.F. Pullen

University of South Australia, Adelaide, Australia

Abstract

The renewal of facilities and infrastructure requires a comprehensive review of many factors so that the most appropriate solution can be selected. The complexity of the decision making process has more recently been increased by the need to consider environmental issues. Using urban water infrastructure as a case study, a method is described which provides additional information to determine a suitable replacement strategy. Analytical techniques have been used including geographical information systems (GIS) and embodied energy calculations to ensure a comprehensive comparison. The methodology used is applicable to other forms of infrastructure or building facilities.

Keywords: asset management, environmental impact, GIS, total energy requirements, urban infrastructure, water services

1 Introduction

This paper concerns the management of urban infrastructure and other facilities such that appropriate decisions are made about the renewal of aged systems and components. The renewal of complete sections of a facility or infrastructure requires a different level of decision making compared with routine maintenance and repair. It gives the asset manager the opportunity to consider new designs based on contemporary developments. A comprehensive approach examines all relevant factors such as flexibility, compliance with regulations, energy efficiency, outsourcing arrangements as well as capital and future maintenance costs.

The complexity of this decision making process has more recently been increased by the need to consider environmental and related issues. In addition to the more conventional aspects of systems choice based on factors such as cost,

Durability of Building Materials and Components 8 (Volume Three). *Edited by M.A. Lacasse and D.J. Vanier*. Published in 1999 by NRC Research Press, Ottawa ON K1A 0R6, Canada. ISBN 0-660-17742-0

performance and durability, there is an increasing obligation to minimise the environmental impact of replacement plant, buildings and infrastructure. This approach requires a more holistic method of considering all the related issues and normally requires life cycle analysis.

The broader context in which appropriate solutions can be found is explored in this paper. Using urban water infrastructure as a case study, a method is described which provides additional information to find a suitable replacement strategy. This method addresses environmental issues which are now forming an increasingly important backdrop for decision making. The approach described can be used for evaluating the renewal or replacement of other forms of infrastructure or building facilities.

2 Environmental obligations

Most government instrumentalities in Australia adopted policies on energy conservation some time ago as a result of the disruptions caused by the oil embargoes of the 1970s. Although driven by economic imperatives at the time, these policies fostered better environmental practice by encouraging energy efficiency. The policies are now being reviewed and enhanced as a result of certain global, national and local environmental initiatives.

An example of these initiatives is Agenda 21 (Halpern, 1992) which was launched by the United Nations Conference on Environment and Development (UNCED) and embraces many activities connected with environmentally sustainable development (ESD). In response to Agenda 21, the Australian Government published the National Report to UNCED (Environment Australia, 1995) highlighting measures and case studies relating to the various facets of ESD such as land resources, agriculture and biological diversity. Action on Agenda 21 issues also applies at a local government level where municipal councils have, for example, undertaken energy and emissions audits on their building and infrastructure (City of Marion, 1998). This will have implications for the repair and upgrading of facilities managed by local councils.

Of major significance to the operation and refurbishment of buildings and facilities is the international agreement on greenhouse gas emissions made at Kyoto in 1998. In connection with this accord, the Australian Government has undertaken a number of actions. As far as housing is concerned, stricter voluntary codes are planned for reducing energy consumption and these may be reinforced using mandatory compliance with standards. There is also a focus on renewable energy development and generation in terms of financial support and demonstration projects. The proposals for offsetting carbon dioxide (CO_2) emissions with tree plantations have significant implications for investment decisions on new or refurbished infrastructure (AACM, 1998).

A Greenhouse Challenge Office has also been established to encourage industries to seek continuous improvements in energy and process efficiency and achieve practicable greenhouse abatement performance. A further example of government organisations taking initiatives is the New South Wales Sustainable Energy Development Authority (SEDA). One of the policies undertaken by this body is the reduction of energy consumption in government buildings by good practice and plant improvement. Hence, environmental impact is now one of the many issues to be considered when upgrading plant or infrastructure.

3 Life cycle energy analysis

The principle of life cycle analysis has been well established for some considerable time with regard to assessing the economic viability of alternative investment strategies. Similarly, it is necessary to take a long term view with regard to environmental effects to ensure that apparent short term advantages are substantiated over the life of the investment. An international set of principles and a framework for life cycle assessment has now been published (ISO 14040,1997) and this provides a tool for the establishment of ecological balances.

There are many measures of environmental impact including greenhouse gas emissions, resource depletion, loss of biodiversity, etc. The assessment of energy consumption is often used as it is relatively easy to quantify and is closely related to carbon dioxide emissions. A comprehensive analysis of energy consumption involves a life cycle approach which includes all of the energy inputs from the commencement of a project to its final demolition. Of the various energy inputs, the operational energy is often the most significant and is traditionally measured as one of the financial costs of running a facility. However, the energy consumed in the manufacture and supply of the materials and components of the facility can also be large. A study of a commercial building in Melbourne (Treloar, 1993) suggested that the embodied energy of the materials in the building was of a similar order to the operational energy over a 40 year life.

In a study of residential construction in South Australia, life cycle energy

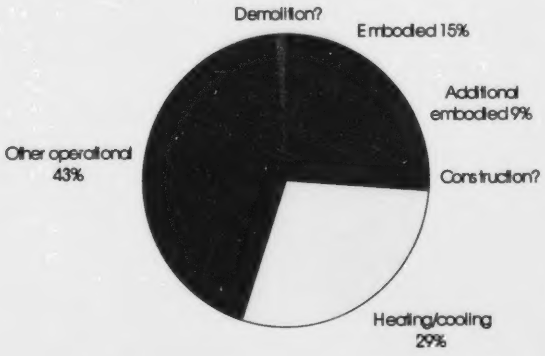


Fig 1: Proportions of energy expended over 80 years for 15 houses.

analyses were carried out on fifteen houses (Pullen and Perkins, 1995). The principal energy inputs of operational and embodied energy were analysed for each dwelling.

Over a life cycle of eighty years, the operational energy was calculated in terms of 'heating/cooling' and 'all other' energy. The embodied energy of the materials of the houses when constructed and as a result of periodic maintenance (eg painting, repair, wet area upgrades) was also estimated. On average, the embodied energy amounted to approximately one quarter of the life cycle energy as can be seen in Figure 1.

As far as managing publicly owned assets is concerned, the decision to refurbish or demolish is given a new dimension when an environmental aspect such life cycle energy consumption is considered. If carbon dioxide emissions are considered, then the future analyses will be particularly interesting as renewable energy devices (with very low CO_2 emissions) replace fossil fuel for operational energy supply.

4 Urban water infrastructure case study

4.1 Background

Modern urban water infrastructure consists of a centralised resource connected to customers by an extensive reticulation system. This description applies equally to water supply, waste/sewage removal and stormwater drainage. New concepts are being introduced which are quite different to the conventional systems and these include on-site rainwater storage, on-site dry effluent treatment, ponding and slow release of stormwater, the aquifer storage and retrieval of stormwater, wetland purification of wastewater, zero coastal discharge of wastewaters, restoration of natural water channels and re-use of treated wastewaters for irrigation and grey water supplies (Perkins, 1997). These new concepts offer both economic and environmental advantages and all aspects must be considered when deciding to renew parts of the infrastructure. Other than the possibility of reduced water consumption and marine pollution, the new systems may also require less energy and associated greenhouse gas emissions. However, the evaluation of such schemes must be comprehensive as apparent improvements may be offset by unseen disadvantages. For example, improvements in energy efficiency may be offset by increased amounts of energy required in the construction of the new system (embodied energy). The first step in such comparisons is the establishment of benchmarks for the conventional design against which new proposals can be compared.

A case study has been undertaken which establishes a benchmark for the total energy requirements of a conventional water system (Pullen et al, 1998). The study was based on a southern suburb of Adelaide, South Australia known as Seaford which consists of approximately 450 dwellings and was constructed between 1992 and 1994. Seaford is principally supplied with water from the Myponga reservoir which is 20km to the south.

Sewage is removed to the Christies Beach treatment plant which is 15km to the north and stormwater is discharged to the nearby ocean via the adjacent Pedler Creek.

4.2 Method

To determine the benchmark for the total energy consumption of the existing water infrastructure, six potential areas of energy consumption were identified as shown in Table 1. These were:

- operational energy i.e. that used on a regular basis for or pumping filtration and effluent treatment and
- embodied energy i.e. that used initially to produce the materials in the physical infrastructure for the three systems under study.

Table 1: Summary of the six potential areas of energy consumption

Energy type	Water Supply	Sewer System	Stormwater System
Embodied	Energy to produce the materials and components from source of water to Seaford house.	Energy to produce the materials and components from Seaford house to treatment plant.	Energy to produce the materials and components from Seaford house to marine outfall.
Operational	Energy to filter, chemically treat and, possibly, pump water	Energy to pump and chemically treat waste.	No energy used.

Operational energy information was collected from the State electricity supplier for power supplied to individual pumps in the water system. Collection of embodied energy information was considerably more involved as the type and quantities of materials in the entire water systems were required. Some of this information for the water supply and sewer systems was available from geographical information system (GIS) files. From GIS maps of Seaford and adjacent areas, it was possible to retrieve data on the length, diameter and material type of water pipes along a chosen path and the number of houses connected to a particular pipe. For other parts of these systems and the storm water system, quantities of materials were calculated manually from specifications and drawings.

Once the quantities of the materials had been calculated, the embodied energy was estimated by means of energy coefficients for each type of material. To avoid differences in the method of derivation of embodied energy coefficients, an independent set based on Australian national economic data was derived using input-output analysis (Pullen, 1995).

To relate the embodied energy to the operational energy for the three systems, it was necessary to annualise the embodied energy of each material and component. This was calculated by means of life expectancy factors as shown in Table 2. These factors are the life expectancies applied by SA Water which is the body managing South Australia's water system.

To relate both the operational and embodied energy of the three water systems to an individual dwelling in the Seaford area, it was necessary to calculate a relevant apportionment factor for each component. For example, the factor for the dwelling's individual water meter was 100% whereas the factor for the Myponga reservoir dam was 0.004% due to fact that this part of the infrastructure was shared by 25000 dwellings. This enabled the total energy for the water systems to be expressed in units of GJ/house/annum.

Table 2: Life expectancy factors.

Component	Life (years)
Services	50
Mains	80-120
Pumping stations	25
Pumps	25
Structures	50
Switchboards	25
Tanks	75
Tank roofs	25
Kerbs	50
Gutters	50
Stormwater structures	50-100

5 Discussion of the results

The annualised energy consumptions for the water systems amounted to O.7, 2.4 and 1.6 GJ/house/annum for the water supply, sewer and stormwater, respectively. These figures are in primary energy terms and include a small component for the energy expended on-site during the construction phase. When these values are combined, the total energy consumption is 4.7GJ/house/annum. To put this into perspective, the total annual energy consumption for a typical house (including embodied energy) in South Australia is approximately 95GJ. Hence, the provision of a comprehensive water system represents a further increase of energy expenditure of about 5%. This is a significant proportion especially when other services such as gas, electricity, communications and roads are considered.

By way of comparison with the other research, the energy consumption results for sewer system only can be expressed as 2.9MJ/kl for the embodied energy, 7.8MJ/kl for the operational energy and 10.7MJ/kl for the combined energies. Hagan & Roberts (1980) derived a value of 2.4MJ/kl for the total energy consumption of a sewer system in California. Diver & Mouritz (1994) noted a value of 0.4MJ/kl for the operational energy consumption of a sewer system in Western Australia. Bearing in mind the likely differences in topography, system type, population served and the known differences in energy analysis methods, the comparisons reveal energy consumptions of a broadly similar order. Other research (Carltech, 1986) reviews the methods of estimating the embodied energy of waste water systems.

As an example of using the energy consumption values as benchmarks for assessing other types of systems, the use of rainwater storage tanks has been considered. Although essential for remote locations, rainwater storage tanks for individual houses are not normally used for providing the water supply in urban areas of South Australia. However, they represent a possible alternative to centralised water storage and supply. The comparison of individual storage tanks with the conventional supply system illustrates the methodology required when considering the renewal of facilities and infrastructure.

Depending on seasonal rainfall variations, catchment area and water consumption for each house, the storage capacity can be determined. The embodied energy for three sizes of a water stage tanks were estimated. Two types of tank were considered, a polyethylene lined profiled steel tank and a reinforced concrete tank as shown in Table 3. Further details of these structures are given in Appendix A.

Table 3: Embodied energy of water storage tanks.

Tank size	PVC membrane lined steel			Reinforced concrete		
	Embodied energy (GJ)	Life expectancy (years)	Annualised energy (GJ)	Embodied energy (GJ)	Life expectancy (years)	Annualised energy (GJ)
34kl (7500 gals)	13	50	0.3	42	75	0.6
68kl (15000 gals)	24	50	0.5	58	75	0.8
113kl (25000 gals)	36	50	0.7	78	75	1.0

Compared with the benchmark of 0.7GJ/house/annum for the conventional urban water supply provided by a large storage reservoir and a reticulated pipe system, the individual water supply using a tank can have a lower or higher energy consumption depending on the size and type of structure. The value of this type of analysis is that it shows an environmental advantage (arising from lower energy consumption and associated carbon dioxide emissions) under certain conditions. Favourable conditions appear to exist for the lined steel storage tanks of lower capacity. This may suggest that individual tank storage of water is more suited to areas of regular rainfall where large storage capacity is not required.

Hence, this type of analysis can indicate whether a possible infrastructure alternative is viable from an environmental viewpoint. A slight extension of this method would provide information on carbon dioxide emissions. The methodology used in this case study provides information on environmental impact. This information should be considered alongside a range of other issues to form a more holistic approach to the selection of alternative solutions for infrastructure renewal.

6 Conclusion

It is now recognised that environmental issues must also be considered when replacing facilities or infrastructure. A life cycle approach to energy consumption can provide useful information in this respect. Using a conventional urban water system as a case study, a method has been developed which establishes a benchmark for the total energy requirements of a facility. This has been used to measure the environmental suitability of a possible alternative system. Decisions regarding infrastructure renewal can now be made in a broader context. A similar methodology could be used for the refurbishment of other forms of infrastructure or building facilities .

7 References

AACM International Pty Ltd, South Australia. (1998) *Greenhouse Challenge Sinks Workbook*. Greenhouse Challenge Office (draft). March.

Carltech Associates Inc. (1986) *Energy in Municipal Wastewater Treatment. An energy audit procedure and Supporting Database. Alternative Methodologies for Estimations of Embodied Energy*. Submitted to U.S. Environmental Protection Agency, Contract No. 68-01-6433. July.

City of Marion. (1998) *City of Marion's Local Agenda 21, Creating a Sustainable Future*. South Australia.

Environment Australia. (1995) *Australia's 1995 Report to the UN Commission on Sustainable Development*. Department of the Environment, Commonwealth Government, April.

Halpern, S. (1992) *Process and documentation. Providence, RI: Academic Council for the United Nations System* (ACUNS). United Nations Conference on Environment and Development.

ISO 14040. (1997) *Environmental management -- Life cycle assessment -- Principles and framework. Edition: 1*, International Standards Organisation, Switzerland.

Perkins, A. (1997) Unpublished paper. *Lifecycle Greenhouse Emissions from Urban Water Systems*. School of Geoinformatics, Planning and Building. University of South Australia. 20th February.

Pullen, S. (1995) *Embodied Energy of Building Materials in Houses*. Masters Thesis. The University of Adelaide. January.

Pullen, S. and Perkins, A. (1995) Energy use in the urban environment and its greenhouse gas implications. *Transactions of International Symposium on Energy, Environment and Economics*. The University of Melbourne November.

Pullen, S., Varley, C., Bruce, D., Perkins, A and Lee, H. (1998) *Evaluating the Energy Requirements of Urban Water Systems*. School of Geoinformatics, Planning and Building. University of South Australia. ISBN 0 86803 280 8. March.

Treloar, G. (1993) Embodied Energy Analysis of Buildings Part 2: A Case Study. *Exedra* Vol. 4 No. 1. Deakin University.

Appendix A

Details of water tanks

Tank type	Capacity (kilolitres)	Capacity (gallons)	Diameter (m)	Height (m)
Steel	34	7500	4.5	2.15
	68	15000	6.7	2.15
	113	25000	8.7	2.15
Reinforced concrete	34	7500	7.3	0.81
	68	15000	7.3	1.95
	113	25000	7.3	2.94

Details of materials

Tank type	Component	Material	Thickness (mm)	Embodied energy (MJ/kg)
Steel	Sides	Profiled steel	0.86	26
	Top	Steel (zincalume)	0.46	26
	Liner sides	Polyethylene membrane	0.6	70
	Liner bottom	Polyethylene membrane	0.6	70
	Base	Sand	150	1
Reinforced concrete	Sides	Steel reinforced concrete	70 - 85	26 (Steel), 1.3 (Concrete)
	Top	Steel reinforced concrete	40	26 (Steel), 1.3 (Concrete)
	Bottom	Steel reinforced concrete	150	26 (Steel), 1.3 (Concrete)

170 TOTAL LIFE-CYCLE COST

D.K. Smith

Naval Facilities Engineering Command, Washington, D.C. USA

Abstract

As designers, we have attempted to look at the life cycle of the building components with varied success. As representatives of facility owners, we need a more comprehensive point of view of the impact that the designer has in the total functionality of the facility over its life. In other words, how does an occupant function within the finished facility? Research has indicated that design can improve workplace productivity from 5% to 35%. Savings of only 3.7% in workplace productivity can pay for the entire facility, including construction, operations and maintenance. What is missing is a holistic facility view as well as the tools necessary to measure and analyze the impact of design improvements on workplace productivity. This can be accomplished using total life cycle costing metrics as well as computer simulation of various alternatives for the workplace being created.

Keywords: life cycle, sustainable design, workplace productivity, simulation, cost estimating, life cycle costing, facility owners

1 The task of expanding the life-cycle

Please discard your previous perceptions of life cycle costing. Total Life Cycle Cost (TLC) is a comprehensive approach to facility cost that focuses on dollars as the primary metric for decisions related to a building to achieve the most effective total package. Designers must ensure that the functions within a facility are optimized through their design. TLC supports all phases of the life cycle but focuses primarily on occupancy. It provides a single contiguous set of cost tools so that data does not have to be re-entered at each phase of the life cycle and comparisons can be made. It is a complex electronic model requiring tools that take advantage of the latest desktop

Durability of Building Materials and Components 8 (Volume Three). *Edited by M.A. Lacasse and D.J. Vanier.* Published in 1999 by NRC Research Press, Ottawa ON K1A 0R6, Canada. ISBN 0-660-17742-0

computing and telecommunications capability. It fully supports current practice but will excel as we move to object oriented design and operations. It is intended for the CEO/CFO of the organization to make strategic decisions as well as to support tactical and operational cost related decisions that involve day to day operations of facilities. The product as described, does not exist today.

Life cycle costing has been a part of the overall cost picture for some time now. Unfortunately it has had little impact on the decision making process to date. Typically the life cycle number is presented in a way that cannot be internalized by the owner. It is not well documented and is presented as a single large number and not as an annualized cost showing peaks as certain items must be replaced over time. Primarily, due to accounting practices, the prevailing attitude seems to be that initial cost issues are here and now and the future will somehow have to take care of itself. Further, it seems that one time initial design and construction costs and the recurring operating costs are not linked. In reality quite the opposite is true. The reality is that the future is now and we have to short change new facilities largely because we can't afford the buildings we designed in the past. This is a Catch-22 situation. The question is how can we break out of this cycle? The answer is that we must expand the original life cycle concept to make it significantly more comprehensive and demonstrate the true impact to the building owner. Only the building owner can pull the industry out of this tailspin. No one else in the building process has as much at stake or can affect the change required in the business process.

Life cycle has traditionally been related to the usable life and cost to maintain various construction materials and pieces of equipment in a building. Recently the concept has been expanded to include the impact such materials have on the environment. While this is a positive step it is still only part of the picture. It still only represents a very small portion of the scope that the designer truly has control over. If misused, the facility might be environmentally correct yet a failure to the owner, based on a poor workplace productivity factor.

There are actually many cycles that a designer can affect in a facility as shown in Figure 1. While there are several items that only occur once in each facility they are repeated by the individual experts on succeeding buildings. Planners, designers and contractors tend to specialize in certain types of projects, because they can take

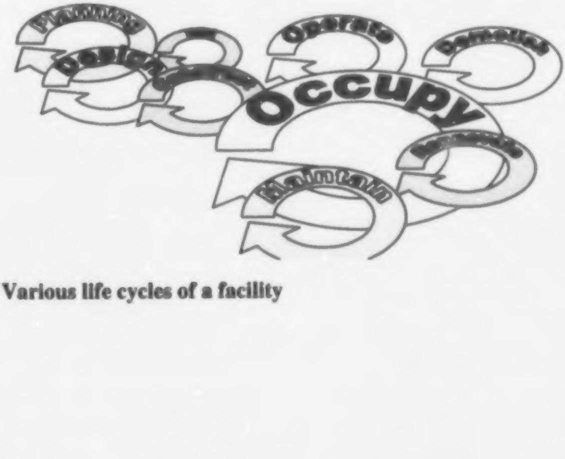


Fig. 1: Various life cycles of a facility

advantage of lessons learned and experience gained. Therefore, they have a cycle they repeat for each facility. Individual facilities also have cycles as employees churn and remodeling occurs or manufacturing processes are retooled. We will examine the relationship of each of these individual life cycles with the total life cycle to include the functions that occur inside the facility throughout its life.

These functions could be mechanical processes as in a manufacturing plant or could be people intensive, as in an office building. A qualitative evaluation of productivity in the workplace must be included in the assessment designers make of the facilities they design. A study done by the Advanced Building Systems Integration Consortium (ABSIC) at Carnegie-Mellon University (Loftness & Hardkoff 1996) indicated that a designer could easily affect productivity by 5 to 35 percent. The study also indicated that improving workplace productivity by only 3.7% could pay for the entire facility. This represents a tremendous untapped potential for improvement. Therefore improving workplace productivity can create essentially "free" buildings. We must collectively foster efforts that target this largely untapped resource.

In order to accomplish this we must have a comprehensive cost analysis tool, something that the industry has not seemed to be able to come up with to date. There have been products over the years that make claims to be comprehensive, yet in reality they still only address a small part of the issue and even those limited scope products have not proven to be fully functional. They end up being black boxes that professionals have trouble trusting.

This paper promotes a total life cycle approach that supports contiguous cost information throughout the entire life cycle of a facility from concept design through occupancy and ultimate demolition. In order for this concept to work, each professional throughout the process must view his or her contribution as only one step along the way in total support of a facility. Information is gained from the professionals that worked previously on the project and the information they collected should be made available to the next professional along the path. A feedback loop must be built in so that constant improvement can occur. This information centric approach was originally portrayed in the Installation Life-cycle Management (ILM) philosophy. However, this proposal primarily focuses on the cost aspect (Smith 1997).

In many instances, such as industrial plants, college and university campuses and military installations, the owner of the facility has to make decisions based on the status of many facilities. The concept proposed is to provide the capability to allow the information from one facility to be combined with other facilities to analyze the entire "campus" or installation. This information centric approach versus a project centric approach has significant potential for making more learned decisions. TLC does not require any additional data collection. In fact it will eliminate a significant amount of redundant data collection. Campus management requires one to know if all the chillers or roofs need to be replaced at approximately the same time so that resource leveling can occur to ensure that all the expense does not need to be absorbed by one year's operating budget. Anticipating or predicting the peaks will reduce the risk that systems will fail unexpectedly which creates crises, typically inconveniencing the occupant and negatively affecting productivity. The decision process can be greatly aided by having specific information about the age and condition of the roofs in order to correctly prioritize the replacements. Cost is the key facet of that decision. Not just the cost of replacement, but also productivity impact cost, or the effect that not doing the project, or the ability to time the project to minimize the negative impact on productivity. This approach will help move one away from a crisis management mentality to planned maintenance. As confidence is gained in the product, the need for a crisis to bring action will diminish. Another reality even more pronounced with today's economy is assessing the impact of delaying repair or replacement. It is normally much less costly to maintain and repair versus replace. The old adage related to changing the oil in one's car should come to mind here – "pay me now or pay me later." The problem is that paying later is a significantly more costly endeavor.

Having energy utilization information available can also indicate when things need to be replaced or modernized. Although the final form of energy is heat, the metric is dollars. Does historical energy usage information indicate that replacement of windows will actually obtain the energy reductions claimed? If you don't have factual information you can only make decisions based on anecdotal hunches. Our goal is to develop a better way.

2 Why the tools do not exist

This is certainly not a new problem and on the surface it is incomprehensible that we don't have some holistic cost analysis tools already available. In discussing this issue with several providers of cost estimating products, it is easy to understand why we are in this predicament. Our industry is very fragmented and there is little communication between the parties involved. The only ones that span all facets of the facilities life, have the most to gain and have the potential to resolve this issue are the building owner. They are the ones that conceive of the project, hire the planner and architect, initiate the contract to build the facility, pay the bills for operation, determine the level of maintenance, decide when to remodel and ultimately decide when to abandon the facility or tear it down. On what basis do owners currently make these decisions? Typically they seek out a professional that is an expert in the specific facet of the overall picture for which their current issue pertains. Those experts provide judgement backed up by tools obtained from software vendors that aid them in answering cost questions for their owner clients. The problem is that they are experts in a relatively narrow field. The providers of the cost tools focus on supporting just one or two of the life cycle facets based on demand from their customers. Figure 2 indicates the relative importance with which each player in the facility life-cycle process views cost. As you can see the only one that has interest throughout is the owner. Every dollar spent has a relationship to profit. Which dollars must be spent and which dollars are overhead and should be targeted for elimination must be clearly identified.

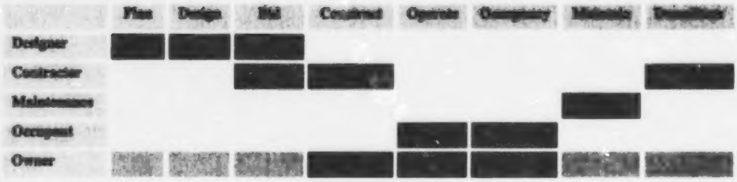


Fig. 2: Level of importance of cost to each participant

The problem with our current fragmented approach is that the big picture is never seen and information has to be recollected at each phase. Due to the cost of data collection only the minimal amount of information necessary to do the job is collected for that phase. Once the information is collected, the report written and the decision made, the process starts over at the next phase with a clean sheet of paper. This leads to significant variances in costs at each phase as well as only snapshots of the entire facilities life cycle cost. Rarely does it take into account productivity, only because no apparent link exists to the expert working on that phase.

One federal agency estimates the cost for new facilities using one commercially available cost database and determines its plant value using another. The problem is that there is a 38% difference between the two databases! How can they expect to make valid decisions concerning the construction of new facilities versus renovating or tearing down the existing facilities? They also have no information at the facility level related to energy costs. The problem is that most of the costs dealt with in one phase are hidden from the others. Not maliciously, but because no one has responsibility for the overall facility. Hence we find situations where steam lines are not repaired because repair dollars are not available while additional steam must be generated due to steam loss. The cost of doing business this way is either passed on to the taxpayer or on to the consumer in higher cost goods. The rare company that does have a handle on this can offer a higher quality product at lower costs and capture a larger portion of their market. Prime examples of this are companies such as USAA Insurance, L.L. Bean and Wal-Mart. Is this then a proprietary or competitive issue? Possibly, but I don't think that we are that sophisticated. I think it is simply because the costs are hidden and the immensity of the issue and the relationships are not recognized. However, as we see in the Carnegie-Mellon study the two have a major impact on each other and are worth obtaining.

3 The immensity of the problem

The owner is interested in producing a product. The function that a facility serves typically is to house a manufacturing process or people. The primary interest of the owner is optimum productivity and a quality product at a low cost. They may have a handle on the operations of their company, but constructing new facilities is viewed as a necessary evil that takes too much time. It is rarely viewed as an opportunity to improve the company's bottom line by improving long-term productivity. Our goal is to highlight that the initial facility expense is an investment in the future and ensure it is seen as an asset. Just like investing in the stock market the quality of the stock is a major factor when related to its return and long term growth.

Optimum productivity in the public sector translates into meeting mission requirements within budget. The designer's primary interest is providing a functional facility to the owner. The problem is that the facility itself only represents a very small portion of the cost of providing the function, yet it will have immense impact on the product in the long run.

Figure 3 takes a snapshot of 100 square feet in an office building and assumes that one person occupies that space. Design, construction, operation, and maintenance represent only 5% of the life-cycle cost yet occupies most of the designer's time. In the case portrayed in Figure 3 the personnel costs represent over 95% of the cost of the facility (Rutherford 1997). This is also true in manufacturing where the value of the product produced must dwarf the cost of the production equipment and the enclosing facility in order to turn a profit. The military has a similar example when they build a $5M hangar to house a half billion-dollar airplane. The fact that the design fee represents less than a tenth of one percent of the TLC is not meant to minimize the importance of the facility or the designer, in fact it is quite the opposite. That relatively small investment in a quality TLC designer may make or break your company, although it will be hard to pin the demise on that factor alone. I contend that it is probably the most important factor. Conversely, having an optimum facility that supports high performance workplace and productivity can still fail with poor management. It still comes down to how you use what you have. If you have an optimum facility and you get the most out of it you will have an easier time obtaining a significantly higher level of success.

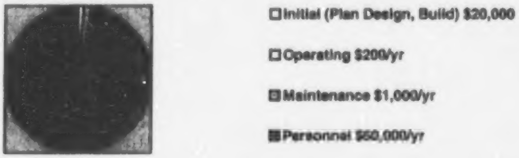


Fig. 3: Functional costs related to facilities (100 SF over 30 years)

Therefore optimizing the design fee at the expense of workplace productivity improvements is extremely misguided. Improving operating costs and reducing maintenance costs do not have as much impact as design issues oriented toward people and improving their productivity.

Actually improving the air quality and lighting and such things can improve both operating costs and productivity because people are healthier and stay on the job longer so win-win situations can be achieved.

If we assume the productivity rule of thumb that one must produce 2.5 times their direct salary, or $150,000 in this case, and if we use the productivity improvements identified in the Carnegie-Mellon study on the figures presented in

Figure 3 improvement in productivity translates into $7,500/person/year at the low end and $52,500/person/year at the high end. Over the 30-year life of the building that could be $1,575,000/person.

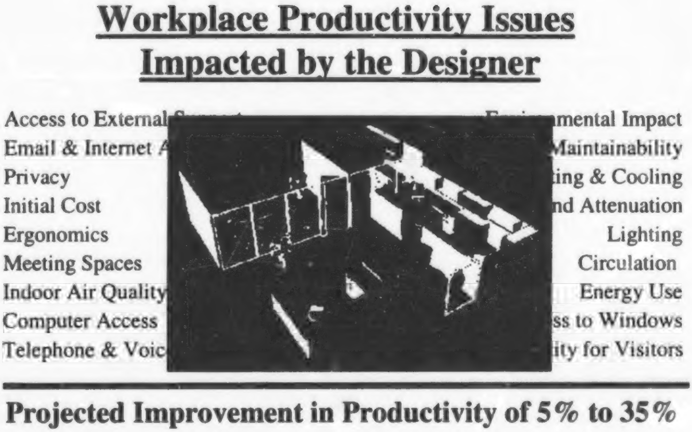
The argument for working close to a job site, or even at home, is also a strong one since a one-hour commute in the morning and at night equals a 40-hour week per month! Reducing the commute improves one's quality of life. Hence the adage location, location, location could translate into a primary key to success. If your organization gets an extra week of productivity out of its people by locating close to where they live, it might just be the edge you need. Even if that 40 hours is spent on their own time they will be happier employees able to produce more while at work. Spending an extra million or two for a piece of property therefore may not be a bad decision. However that must be evaluated in the overall picture. None of these opportunities stand alone yet potential workplace productivity savings are found in all aspects of design decision making.

The designer does have the potential to control the items identified in Figure 4. Figure 4 identifies over a dozen items that must be taken into account when looking at workplace productivity. Most are routinely looked at from the initial cost aspects but rarely are they looked at from the productivity point of view. This is mostly because the designer does not have the tools to make productivity related decisions, or the training. Either the data must come from owners or research most likely paid for by owners.

Unfortunately, most projects do not take all this into account in a holistic approach. Often this is because we have little data to support one choice over another. In many cases it is more expensive initially to provide individual temperature controls or enclosed offices. But as you can see from our example in Figure 3 even doubling the initial cost of the space would have little effect on the overall outcome. In many cases providing enclosed offices with sensors to tell when they are occupied will save significant energy costs as lights can be turned off and temperatures can be lowered. This points out the need for expanded workplace productivity studies such as the ones being carried out by ABSIC.

Many of these issues are incorporated into new policy that is being heralded by the White House. The concept of Sustainable Design (Emmons 1998) takes into account the impact that building materials have on the environment. Not only the initial impact, but also the impact of their manufacturer, usage and disposal. This concept is now policy at the Naval Facilities Engineering Command thanks to the efforts of Mr. Terry Emmons.

We are making progress in moving beyond the traditional life-cycle issues with work being done at the National Institute of Standards and Technology (NIST). The work being done there by Barbara Lippiatt on the Building for Environmental and Economic Sustainability (BEES) model (Lippiatt 1998) demonstrates the impact of using various building products. BEES measures the economic performance of building products by using the environmental life-cycle assessment approach specified in the latest version of the ISO 14000 draft standard. This effort is looking at how we can build with renewable resources and make our facilities friendlier to the environment all around, a factor of large proportions and worldwide impact.



Workplace Productivity Issues Impacted by the Designer

- Access to External
- Email & Internet
- Privacy
- Initial Cost
- Ergonomics
- Meeting Spaces
- Indoor Air Quality
- Computer Access
- Telephone & Voic
- mental Impact
- aintainability
- ing & Cooling
- nd Attenuation
- Lighting
- Circulation
- Energy Use
- ss to Windows
- ity for Visitors

Projected Improvement in Productivity of 5% to 35%

Fig. 4: Designer effected productivity

Another field of study that can greatly aid the designer in predicting workplace productivity is simulation. The work being done by Carson Benson shows very significant potential, especially on complex facilities (Bensen 1998). Simulation is not the same as visualization. In simulation one can "walk" electronic figures through a facility to indicate places where they would go in carrying out daily business functions. An example would be an emergency room. By simulating the movements of say 100 people potentially based on actual cases you can easily identify choke points or areas that are underutilized. In one such example they determined the need for fewer interview rooms and more examining rooms due to predicted backlogs. These are workplace productivity issues.

All these efforts are part of the patchwork quilt that we call construction. What is needed is a unifying element and the argument that encourages it to happen.

4 Achieving Results

No one organization or company can solve this issue and produce the comprehensive product required. We have proven that over the last 2000 years. Therefore a different approach must be undertaken. I propose that an international consortium be formed bringing together top estimating firms and experts involved in all the facets of facility cost engineering, planning, design, construction bidding and change orders, operating, maintenance, insurance, lending, etc. The group calling this group of experts together would be the owners. The issues we are dealing with are common to all developed countries in the world and the benefits will be for all. There are some truly outstanding niche products available throughout the world. However none that I know of link together to allow information to flow from one phase to the next all the way from concept to providing analysis to when it is time to demolish. Certainly there are none that look at workplace productivity improvement issues. In some cases planning can talk to design and design can talk to construction but that is about the extent of our collective capability. A working group must be created for the primary estimating phases of planning, design, construction, operations and maintenance. Two additional groups would represent the financial interests of banking and insurance. There should be an information utility group responsible for identifying the data elements and links needed to accomplish the overall goal.

A board made up of ten leading facility owners, government experts and representatives from the college and university community would steer the group.

Funding for the effort would come from pooled resources from the primary beneficiaries, industry and public-sector building owners. Organizations that participated in the development would be able to use the tool at reduced rates based on their investment. Others would have to pay the full usage fee. The usage or license fee would have to be based on fair market value, and that could be fairly significant over time based on validated payback to the end users. The team should be able to accomplish its efforts in less than two years and the total cost should be approximately two million dollars. Most of this expense would be focused on data collection since most of the algorithms already exist. Assuming the ten board members each provided $100,000 and there were 200 additional owners that each contributed $10,000 the funding needed could easily be attained.

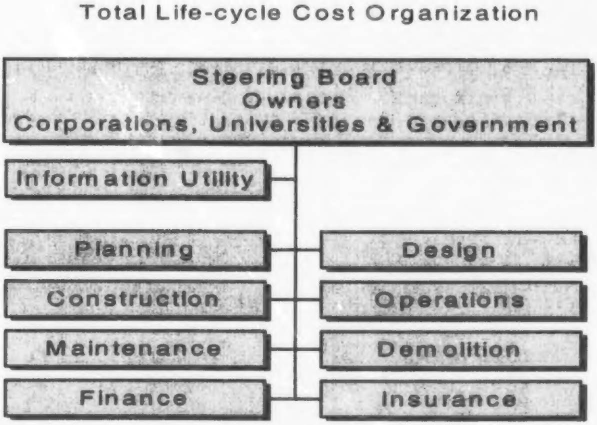


Fig. 5 - Organizational structure

The product must be completely open for understanding by the professionals at each stage. There can be no hidden operations or algorithms. There would be little worry of someone copying the initiative based on the investment and the coordinating effort required. The data could be proprietary and offered by various companies for different portions of the life cycle. Once the product was developed it could be linked to other efforts such as the International Alliance for Interoperability (IAI) and it could easily stay ahead of any competition.

What is missing at this point is a proponent to start the ball rolling. Someone must be willing to invest some time and money to host the groups and provide the logistic support to allow this to occur. The primary candidate would be a large facility owner who would have a lot to gain from having such a product.

5 Summary

In conclusion, it is essential that we produce a comprehensive product that will allow a planner or owner to sketch out a proposed facility and immediately have a rough idea of all of the costs as well as the workplace productivity benefits. This will give them a clear idea of their potential return on their investment. The designer will be able to take that information and develop a design that will accomplish the goals established. The designer will then be able to evaluate alternative designs to ensure that all aspects are optimized. The electronic cost model will ultimately be linked to an object oriented design. The electronic model will be passed to a contractor to provide a bid for construction. An alternative here would be a design build arrangement in which the cost model would be shared as the design develops. Once the contractor is chosen and construction begins final information from the vendors of the products would be included with the model. This information would then be passed on to the operator and maintainer of the facility. Metrics would be monitored to ensure that the facility was working according to design and that the productivity enhancements were being realized. Failures would be made available to the owner as well as a lessons learned database for future projects. Adjustments would be made as needed to enhance the productivity and to ensure that the facility operated as expected throughout its life. As the knowledge base improved the facility could be checked against potential new facilities to see if a new facility would improve productivity and then the old one could be demolished or recycled. All this is possible if we are really serious about improving quality of life and productivity.

6 About the author - Mr. Dana K. "Deke" Smith, AIA

Mr. Smith is currently Deputy Director for Y2K Embedded Technology and Advanced Technology Development at the Naval Facilities Engineering Command. Mr. Smith is a registered architect in the state of Virginia. He recently completed the DoD/Joint Senior Executive Leadership Course (SELC). Prior to that he was Director of the Engineering Support Systems Division of the Naval Facilities Engineering Command. Mr. Smith was selected as one of the 1996 "Federal 100" by Federal Computer Week. He was the 1997 recipient of the National Institute of Building Sciences Member Award for the most significant contribution to the building industry. He was recognized for his efforts in spearheading the development of the U.S. National CADD Standard. Mr. Smith is the United States representative to International Standards Organization (ISO) for construction related CAD. He was the Federal Government representative on the GSA National Workshop on Improving Productivity in the Workplace.

7 References

Bensen, C. (1998) Architectural Simulation, Federal Facilities Council Symposium, National Academy of Sciences.
Emmons, T. (1998) Suststainable Design Policy.
Lippiatt, B.C. (1998) "Building for Environmental and Economic Sustainability (BEES)", CIB World Congress 1998: Construction and the Environment.
Loftness, V. and Hardkoff, V. (1996) Advanced Building Systems Integration Consortium, Carnegie-Mellon University.
Rutherford, Thomas R. (1997) Workplace Productivity, American Military Engineer Magazine.
Smith, Dana K. (1997) "Installation Life-cycle Management", Journal of Computing in Civil Engineering, Vol. II, No. 2.

171 FACILITY LIFE-CYCLE COST ANALYSIS BASED ON FUZZY SETS THEORY

J.O. Sobanjo

FAMU-FSU College of Engineering, Tallahassee, FL, USA

Abstract

This paper presents the framework of a fuzzy sets-based methodology for life-cycle cost analysis of facilities, including application to buildings. Life-cycle cost analysis is a major phase of facility management and value engineering. Facility components and materials deteriorate at different rates and require some form of maintenance, rehabilitation, and replacement (improvement efforts) throughout their service lives. It is difficult to estimate the timing of these improvement efforts, i.e., the expected service lives of the materials at the end of which they have to be replaced or a point in the life at which they have to be rehabilitated. The timing of the required improvement efforts can be predicted from deterioration models or estimated subjectively based on expert opinions. The costs of required maintenance, rehabilitation, and replacement may be obtained from historical data but these cost estimates have to be sometimes supplemented with expert opinions in order to perform life-cycle analysis. Representing these variables in the form of crisp numbers and fuzzy numbers, an algorithm is presented to formulate a methodology for life-cycle cost analysis of buildings. Fuzzy sets theory has been proven as a valuable tool for handling uncertainties due to subjective estimates in decision making models. Alternative building designs can be evaluated and compared early in the project development stage.

Keywords: facilities, life-cycle costs, fuzzy sets, rehabilitation, facility management.

Durability of Building Materials and Components 8 (Volume Three). *Edited by M.A. Lacasse and D.J. Vanier*. Published in 1999 by NRC Research Press, Ottawa ON K1A 0R6, Canada. ISBN 0-660-17742-0

1 Introduction

The importance of facility management, in terms of concern about conditions of buildings has been demonstrated by the recent development of deterioration models [Lee and Aktan 1997] and condition indexing methodology [Uzarski and Burley 1997]. Once the deteriorated state of a building component is known, some form of maintenance or improvement (rehabilitation or replacement) is necessitated. Monitoring the costs and timing of these necessary actions over the life of the building constitute life-cycle cost analysis which in turn is a primary aspect of facility management. Traditionally, estimates of initial costs, maintenance costs and improvement costs, expected service lives, and timing of the actions have been done based on historical analysis of data. It is common however to adjust these estimates, usually the average estimate, with expert opinions, thereby making the estimate subjective. The traditional concepts of probability theory can also be applied to life-cycle costing, treating the costs and timings as a stochastic process. In this case the variables have to be estimated purely from a historical data in order to satisfy the assumptions of the randomness. If any subjectivity is introduced to the estimates, then the uncertainty cannot be handled using the probability theory alone. Fuzzy sets theory is a valuable tool for handling such uncertainties. Representing the estimates of the decision variables required as fuzzy numbers, this paper presents a methodology for handling the subjective uncertainty in life-cycle cost analysis.

2 The concept of fuzzy numbers

Consider a set **A** with elements denoted by x. Under the conventional set theory, a characteristic or membership grade function μ_A can be used to define the membership of any element or subset in the set **A** as follows:

$$\mu_A(x) = \begin{cases} 1 \text{ if } x \ 0 \ A \\ 0 \text{ otherwise} \end{cases} \qquad (1)$$

Instead of the {0,1} (yes or no) valuation, if the membership grade $\mu_A(x)$ can have values in the real interval [0,1] according to how much x belongs to this set **A**, then the set **A** is a fuzzy set [Zadeh 1965]. If the set **A** is a set of criteria, $\mu_A(x)$ is the degree to which x satisfies the conditions of A, or in other words, $\mu_A(x)$ is the "strength" of the statement : "x belongs to the set **A**." In fuzzy sets terminology, values that are known precisely, are referred to as crisp ordinary numbers, while imprecise values are represented by fuzzy subsets. In the methodology proposed in this paper, the fuzzy sets concept is applied to deal with the imprecision in quantitative values which are subjectively estimated. Decision variables are represented as fuzzy numbers while algebraic computations will be based on the interval of confidence or interval arithmetic described by Kaufmann and Gupta [1985]. Under this approach, the ∀-cut or intervals of confidence of the fuzzy numbers are used to perform the necessary algebraic operations. Basic fuzzy sets theory textbooks and papers explain the general form of a fuzzy subset A where ∀ is the degree of belief, or in terms of fuzzy sets, the degree of membership. $A_\forall$, the interval of confidence associated with ∀ is formally referred to as the V-cut. All possible values of A whose degrees of belief are greater than or equal to a specified value ∀ constitute the ∀-cut $A_\forall$, such that

$$A = [x| \mu_A(x) \exists \forall] \tag{2}$$

A simple form of fuzzy number is the triangular fuzzy number (TFN) with a triangular distribution as the membership function. Using three parameters *l, m, and h*, a TFN can be adequately expressed as a triplet *[l, m, h]* where *[l, h]* is the largest ∀-cut and *m* is the modal point. The mode *m* of a TFN is the most possible value under the distribution while *l and h* represent the lowest and highest possible values respectively. The support is estimated as *(h - l)*.

The membership function of TFN **A**, where **A** = *[l, m, h]*, can be defined as:

$$\begin{array}{lll} \mu_A(x) = & 0, & x < l \\ = & \frac{x - l}{m - l} & l > x < m \\ = & 1, & x = m \\ = & \frac{h - x}{h - m} & m > x < h \\ = & 0, & x > h \end{array} \tag{3}$$

In the life-cycle costing methodology, it will be necessary to make decisions based on the ranking or comparison of costs of facility alternatives, estimates which are of the form of TFNs. The comparison of TFNs can be mathematically done using two approaches: first, a linear ordering or ranking of the fuzzy numbers based on an equivalent crisp ordinary number; and a "qualified comparison" approach in which the "strength" or "truth values" of the resulting decisions are indicated by the ∀-cuts of the fuzzy numbers.

Kaufmann and Gupta [1988] discussed the linear ordering of fuzzy numbers using an index called the "removal" or "ordinary representative" of each fuzzy number — the crisp ordinary number equivalent. The "ordinary representative" of a TFN **A** = *[l, m, h]* or A^{ORD} can be computed as

$$A^{ORD} = \frac{(l + 2m + h)}{4} \tag{4}$$

The second approach is the "qualified comparison" approach as mentioned earlier. To compare two TFNs **A** and **B**, a "qualified" statement can be made on the relative value of the property represented by these fuzzy numbers. If **A** and **B** respectively denotes the TFN distributions of the numerical values of a property being used to measure and compare two objects (figure 1), then by graphically comparing **A** and **B**, a "truth value" can be attached to a statement as to whether one object is better than the other [Watson et al. 1979; Whalen 1987]. Consider the ∀-cut at which the inside reference lines of the fuzzy distribution intersects. This intersection is at a membership μ_1. By studying the possible values whose degrees of membership (∀) are greater than μ_1, i.e., ∀-cut at μ_1, it could be seen that the lowest possible value for B is higher than the highest possible value for A. Using this standard of possibility ($\forall = \mu_1$), it could be said that the property value of B is strictly greater than the property value of A. The "strength" of this statement or its "truth value of strict dominance" is given by the compliment of the lowest degree of membership (∀) above which the statement is true [Whalen 1987]. Thus, the statement "B has a better property than A" has a "truth value" of $1 - \mu_1$, or 0 as denoted in figure 1.

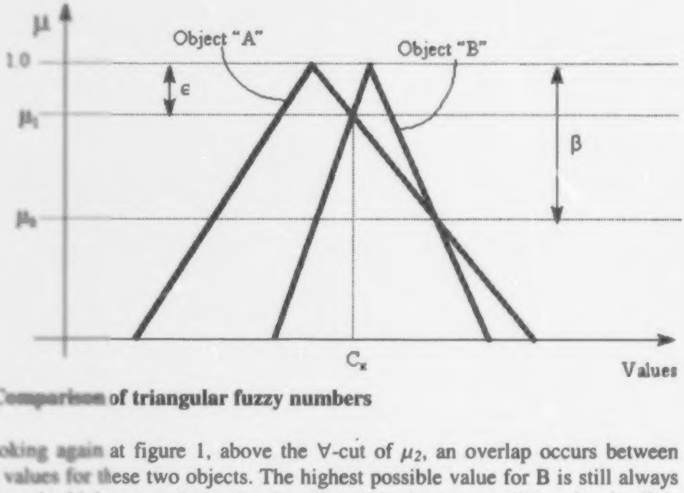


Fig. 1: Comparison of triangular fuzzy numbers

Looking again at figure 1, above the ∀-cut of μ_2, an overlap occurs between possible values for these two objects. The highest possible value for B is still always higher than the highest possible value for A, and the lowest possible value for B is still higher than the lowest possible value for A, but the lowest values of B are not higher than the highest values of A. Thus, the statement "B has a property at least as good as A" has a "truth value" of $1 - \mu_2$, or ∃ as denoted in figure 1.

The "truth value" mentioned above can be computed from the graphical relationship of the TFNs. Consider any two TFNs **A** and **B**, where $\mathbf{A} = [l_1, m_1, h_1]$, and $\mathbf{B} = [l_2, m_2, h_2]$. If $m_2 > m_1$, then the "truth value of strict dominance" as discussed above, can be derived from the possibility level μ_1 at which left reference function of **B** intersects with the right reference function of **A** (figure 1). Above this level μ_1, all possible values of **B** are greater than all possible values of **A**. The desired "truth value" is simply the complement of μ_1. Looking at figure 1, the *x* coordinate of the intersection point, say C_x, can be computed as follows:

$$C_x = \frac{h_1(m_2 - l_2) + l_2(h_1 - m_1)}{(h_1 - m_1) + (m_2 - l_2)} \tag{5}$$

Then,

$$u_1 = \frac{h_1 - x'}{h_1 - m_1} \tag{6}$$

Therefore, the "truth value of strict dominance" can be computed as:

$$0 = 1 - \mu_1 \;=\; \frac{1}{h_1 - m_1} \left\{ \frac{h_1 m_2 - m_1 l_2}{(h_1 - m_1) + (m_2 - l_2)} - m_1 \right\} \tag{7}$$

Based on the concept of interval arithmetic [Kaufmann and Gupta 1988], the following fuzzy mathematical operations may be pertinent to the proposed methodology of life cycle costing. Assume a crisp ordinary number, k, a TFN **A** $= [l_1, m_1, h_1]$, and a TFN **B** $= [l_2, m_2, h_2]$.

1. Multiplication of a TFN by a Crisp Ordinary Number:

$$k \,\theta\, A \;=\; k \,\theta\, [l_1, m_1, h_1] \;=\; [kl_1, km_1, kh_1] \tag{8}$$

2. Division of a Crisp Ordinary Number by a TFN

$$\begin{aligned} k \,\tau\, A &= k \,\theta\, A^{-1} \;=\; k \,\theta\, [l_1, m_1, h_1]^{-1} \\ &= k \,\theta\, [1/h_1, 1/m_1, 1/l_1] \\ &= [k/h_1, k/m_1, k/l_1] \end{aligned} \tag{9}$$

3. Division of a TFN by a Crisp Ordinary Number

$$\begin{aligned} A \,\tau\, k &= A \,\theta\, k^{-1} \;=\; [l_1, m_1, h_1] \,\theta\, [1/k] \\ &= [l_1/k, m_1/k, h_1/k] \end{aligned} \tag{10}$$

4. Division of TFNs

$$A \,\tau\, B = [l_1/h_2, m_1/m_2, h_1/l_2] \tag{11}$$

5. Addition of TFNs

$$A \,\rho\, B = [l_1 + l_2, m_1 + m_2, h_1 + h_2] \tag{12}$$

6. Multiplication of TFNs

$$A \,\theta\, B = [l_1 * l_2, m_1 * m_2, h_1 * h_2] \tag{13}$$

3 Fuzzy sets algorithm for life-cycle cost analysis

Life-cycle cost analysis can be simply defined as an economic evaluation of a facility or alternative facilities over a desired service life, taking into consideration, all the costs incurred and benefits gained by the owner over this period, before computing an "equivalent cost" estimate. These costs include the following general classes: initial costs, maintenance costs (annual), future costs (singular), and salvage value. The "equivalent cost" estimate is computed by converting the stream of all the time-related costs to a single equivalent value such as the present worth, annual worth, and future worth. Investment in a facility can then be evaluated or compared with an alternative design, using any of these "equivalent costs" as found appropriate. This paper will use the present worth as the "equivalent cost", to be derived from the following equations which can be found in most economic analysis textbooks:

$$P = F(1 + i)^{-n} \tag{14}$$

$$\begin{aligned} P &= A \ \{\frac{(1 + i)^n - 1}{i(1 + i)^n}\} \\ &= [A/i][1 - (1 + i)^{-n}] \end{aligned} \tag{15}$$

$$P = CI \tag{16}$$

where,

P = Present worth equivalent
F = Single future cost
A = Annual uniform series of costs
i = interest rate
n = economic horizon being considered
CI = Initial cost

Based on equations 14, 15, and 16 above, the traditional life cycle cost algorithm for computing the Present Worth Costs of a stream of present, annual, and future costs is given as:

$$P = 3[\mathrm{CI}] + \ 3\,[F(1 + i)^{-n}] + \ 3\,[A/i][1 - (1 + i)^{-n}] \tag{17}$$

The first component on the right hand side of equation 17 represents the sum of initial costs. The second and third components are anticipated single future costs and annual uniform costs respectively, with each component factorized to convert future costs to a present worth equivalent, i.e., using the interest rate to express the time value of money.

Representing all variables as TFNs except the interest rate i and the economic horizon, n, which are treated as crisp ordinary numbers, the following algorithm is formulated for computing the fuzzy number (TFN) estimate of the Present Worth of a stream of a facility's life cycle costs:

$$[P_l, P_m, P_h] = 3\,[CI_l, CI_m, CI_h] + 3\,[F_l, F_m, F_h](1+i)^{-n}] \\ +\; 3\,[A_l, A_m, A_h]\,[\,i^{-1}]\,[\,1-(1+i)^{-n}] \qquad (18)$$

The variables are same as defined earlier for equations 14 - 16 except for the addition of subscripts indicating the triplet *l*, *m*, and *h* for a TFN.

4 Numerical application

An example is used in the following section of the paper to demonstrate the applicability and usefulness of the proposed life cycle costing methodology. Dell'Isola [1982] provided a simple example for a facility's life cycle costs; initial costs are given for an original design of the facility, along with those of two alternative designs. Improvement efforts such as replacement of facility components or overhauls will be necessary at one or two of three different times for each of the choices. An economic life of 20 years is used, at the end of which the facility will be demolished with an expected salvage (net) value as indicated for each option of facility design. The costs used in the Dell'Isola [1982]'s original example have been utilized here by adopting the exact values as the modes of TFN but introducing uncertainty through the addition of lower and upper bounds to the modes, thereby generating triangular distributions. Interest rates and timings were retained as crisp numbers. The complete analysis is summarized in table 1.

Applying equations 8 - 13 for pertinent fuzzy sets operations and equations 14 - 18 as described earlier for the proposed algorithm, calculation of the Present Worth Cost for the "Original Design" and the two alternatives "A" and "B" are presented in Appendix A at the end of the paper.

The mode of the Present Worth Cost TFN, defined earlier as the most likely value (*m* from the triplet *[l,m,h]*) is actually the value obtained if the life-cycle cost analysis had been done without incorporating any uncertainty, i.e. the traditional algorithm [Dell'Isola 1982]). The modes for the original design is computed in this paper as \$1,458,558 while those of alternatives A and B are \$1,290,230 and 1245.639 respectively. Using equation 4 the ordinary representative (ORD) of PW Costs for the original design is estimated as

$$PW^{ORD}{}_{(ORIG)} = \{1282.240 + 2(1458.558) + 1760.407\}/4 \\ = 1489.941$$

Table 1: Fuzzy sets analysis of facility costs ($1,000's)
(Assume Economic Life = 20 yrs. Interest Rate = 10%)

Costs	Original Design	Alternative A	Alternative B
Initial Costs	[900,1000,1200]	[600,700,850]	[750,900,1100]
Rehabilitation I at Year 8	[0,0,0]	[150,200,210]	[0,0,0]
Rehabilitation I at Year 10	[0,0,0]	[0,0,0]	[18,20,25]
Rehabilitation II at Year 16	[8,10,14]	[175, 200,240]	[0,0,0]
Sale/Demolition* at Year 20	[(75),(80),(88)]	[(90),(100),(125)]	[(71),(75),(89)]
Operating (Annual)	[26,30,35]	[30,35,37]	[22,25,29]
Maintenance (Annual)	[20,25,32]	[17,20,26]	[12,16,23]
Present Worth (PW) Cost	[1282.2,1458.6,1760.4]	[1094.8,1290.2,1518.0]	[1035.9,1245.6,1539.1]
Ord. Rep. of PW Cost TFN	1489.9	1298.3	1266.6
Rank by Ord. Rep.	3	2	1
Life Cycle (PW) Savings	—	191.6	223.3
Mode of PW Cost TFN	1458.6	1290.2	1245.6
Rank by Mode	3	2	1
Life Cycle (PW) Savings	—	168.4	213.0
"Truth value of strict dominance"	0.45	0.09	—

Example adopted and modified from Dell'Isola (1982) — p126.
*Salvage values (positive cash flow)

Through similar computations, the ORD of the alternatives A and B were obtained as $1,298,324 and $1,266,571 respectively. Table 1 shows a summary of this analysis along with a ranking of the alternatives. With an objective of minimizing Present Worth Cost and based on the ORD of the computed TFN PW Costs, alternative "B" is the "best," followed by alternative "A," and lastly, the "Original design." The estimated PW costs as indicated by the ORD implies a higher cost for each facility than the corresponding modes, e.g., for the "Original Design," the ORD PW Cost is about $31,000 higher than the mode. Since the ORD is an "expected" value incorporating uncertainties, this higher cost estimate appears to be more realistic.

Considering the modes of the computed TFN PW Costs, with the same objective of minimizing Present Worth Cost, the rank of preference is the same, i.e., alternative "B" is the "best," followed by alternative "A," and lastly, the "Original design." The issue now is how much better is "B" over the other two alternatives. This question can be answered by the "qualified comparison" approach theoretically described earlier in this paper and illustrated in figure 1. For the numerical example just presented, the "qualified comparison" is shown in figure 2, with TFNs graphically representing the cost distribution of each alternative's cost.

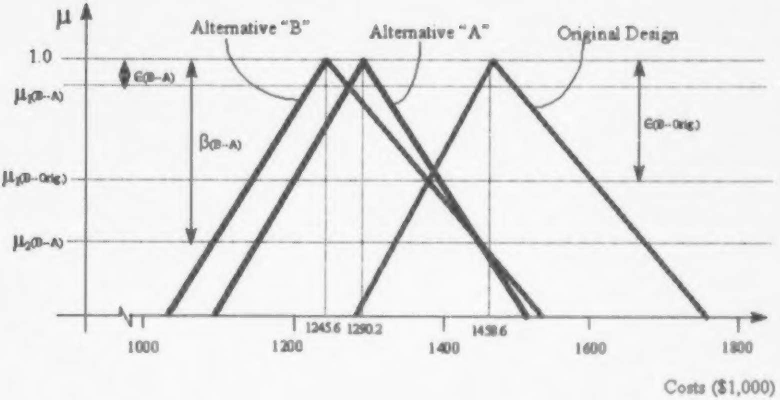


Fig. 2: Comparison of present worth costs (Triangular fuzzy numbers)

Considering "B" versus "A" as shown in figure 2 and employing equations 5 - 7, the following parameters can be computed:

$$C_x = \frac{(1539.1)(1290.2 - 1094.8) + 1094.8(1539.1 - 1245.6)}{(1539.1 - 1245.6) + (1290.2 - 1094.8)}$$
$$= 1272.4$$

$$\mu_{1(B--A)} = \frac{1539.1 - 1272.4}{1539.1 - 1245.6}$$
$$= 0.91$$

$$0_{(B--A)} = 1 - 0.91$$
$$= 0.09$$

Considering "B" versus "Original Design,"

$$C_x = \frac{(1539.1)(1458.6 - 1282.2) + 1282.2(1539.1 - 1245.6)}{(1539.1 - 1245.6) + (1458.6 - 1282.2)}$$
$$= 1378.6$$

$$\mu_{1(B--Orig.)} = \frac{1539.1 - 1378.6}{1539.1 - 1245.6}$$
$$= 0.55$$

$$\begin{aligned} 0_{(B\text{-}Orig.)} &= 1 - 0.55 \\ &= 0.45 \end{aligned}$$

These computed parameters for the "truth value of strict dominance" indicate that the statement "Alternative B is strictly better than A" has a truth value of 0.09 despite the amount of life-cycle cost savings of $168,4000. Also the truth value of the "Alternative B is strictly better than Original design" is 0.45 despite the amount of life-cycle cost savings of $213,000. Obviously, despite the amount of life-cycle cost savings, these truth values are not very comforting. The traditional life-cycle cost analysis, relying on the crisp single value of costs (represented by the mode in the TFN triplet) would have indicated a clear advantage of alternative "B" over the other choices, with savings in the costs. This may turn out to be a misleading decision. If the subjective uncertainties are incorporated as described in the proposed life cycle cost analysis algorithm, a better and more realistic decision can be made.

5 Conclusion

A conceptual methodology has been presented to illustrate how the uncertainties introduced due to subjective estimating of cost variables, typically based on expert opinions, can be handled in life cycle cost analysis of facilities. Utilizing fuzzy numbers to represent decision variables will enhance life cycle cost computations to obtain realistic values for evaluation and comparison of facilities. Simply choosing an alternative as being "better" than the others, based on the traditional approach of life cycle costing, may not be strictly correct. In other words, the confidence of the decision maker's choice depends on the level of uncertainty in the variables considered. This paper has developed a method to estimate such measure of confidence. By reducing the level of subjective uncertainties in the input variables, a more comfortable "truth value of the dominance" of one alternative over the other may be obtained. This will be a better and more realistic decision.

6 References

Dell'Isola Alphonse (1982) Value Engineering in the Construction Industry, Third Edition, Van Nostrand Reinhold Company, New York.

Kaufmann, A. and Gupta, M. M. (1985) Introduction to Fuzzy Mathematics - Theory and Applications, Van Nostrand Reinhold Company, New York.

Kaufmann, A. and Gupta, M. M. (1988) Fuzzy Mathematical Models in Engineering and Management Science, Elsevier Science Publishers B. V., The Netherlands.

Lee, Jin H. and Aktan, Haluk M. (1997) *A Study of Building Deterioration*, Proceedings of the Infrastructure Condition Assessment: Art, Science, and Practice, American Society of Civil Engineers (ASCE), pp 1-10.

Uzarski, Donald, R. and Burley, Laurence A. (1997) *Assessing Building Condition by Use of Condition Indexes*, Proceedings of the Infrastructure Condition Assessment: Art, Science, and Practice, American Society of Civil Engineers (ASCE), pp 365-374.

Watson, S., Weiss, J., and Donnel, M. (1979) *Fuzzy Decision Analysis*, IEEE Trans. System, Man., and Cybernetics, SMC-9.

Whalen, T. (1987) *Introduction to Decision Making Under Various Kinds of Uncertainty*, Optimization Models Using Fuzzy Sets and Possibility Theory, Theory and Decision Library, Series B: Mathematical and Statistical Methods, Kacprzyk, J. and Orlovski, S. A. (eds), D. Reidel Publishing Company, Holland.

Zadeh, L. A. (1965) *Fuzzy Sets*, Information and Control, 8, 338-353.

Appendix A

Present Worth Cost Calculations with Fuzzy Numbers

$$\begin{aligned}
PW_{(ORIG.)} &= [900,1000,1200] \\
&+ [0,0,0][(1+0.10)^{-8}] \\
&+ [0,0,0][(1+0.10)^{-10}] \\
&+ [8,10,14][(1+0.10)^{-16}] \\
&- [75,80,88][(1+0.10)^{-20}] \\
&+ \{[26,30,35]/0.10\}\{1-(1+0.10)^{-20}\} \\
&+ \{[20,25,32]/0.10\}\{1-(1+0.10)^{-20}\}
\end{aligned}$$

$$\begin{aligned}
&= [900,1000,1200] \\
&+ [0,0,0] \\
&+ [0,0,0] \\
&+ [1.741,2.176,3.046] \\
&- [11.145,11.888,13.077] \\
&+ [221.364,255.420,297.990] \\
&+ [170.280,212.850,272.448]
\end{aligned}$$

$$= [1282.240,1458.558,1760.407]$$

$$\begin{aligned}
PW_{(A)} &= [600,700,850] \\
&+ [150,200,210][(1+0.10)^{-8}] \\
&+ [0,0,0][(1+0.10)^{-10}] \\
&+ [175,200,240][(1+0.10)^{-16}] \\
&- [90,100,125][(1+0.10)^{-20}] \\
&+ \{[30,35,37]/0.10\}\{1-(1+0.10)^{-20}\} \\
&+ \{[17,20,26]/0.10\}\{1-(1+0.10)^{-20}\}
\end{aligned}$$

$$= [1094.839,1290.230,1517.996]$$

$$\begin{aligned}
PW_{(B)} &= [750,900,1100] \\
&+ [0,0,0][(1+0.10)^{-8}] \\
&+ [18,20,25][(1+0.10)^{-10}] \\
&+ [0,0,0][(1+0.10)^{-16}] \\
&- [71,75,89][(1+0.10)^{-20}] \\
&+ \{[22,25,29]/0.10\}\{1-(1+0.10)^{-20}\} \\
&+ \{[12,16,23]/0.10\}\{1-(1+0.10)^{-20}\}
\end{aligned}$$

$$= [1035.864,1245.639,1539.141]$$

PART THIRTEEN

PERFORMANCE AND SERVICEABILITY OF BUILDINGS — W60 WORKSHOP

172 THE USE OF PERFORMANCE AND DURABILITY DATA IN ASSESSMENT OF LIFE TIME SERVICEABILITY

T. Anderson and E. Brandt

Danish Building Research Institute, Hoersholm, Denmark

Abstract

Data regarding the performance and service life of buildings and building products are of utmost importance when assessing the serviceability of buildings. A well developed methodology is available when it comes to the selection of building materials and components based on performance requirements while this is not the case when it comes to the function of entire buildings. This is due to the fact that the performance of entire buildings is far more complex.

The paper discusses the problems in assessment of life time serviceability of entire buildings, i.e. the ability of the entire building including materials, components, rooms etc. to function properly over the entire service life. It makes suggestions on how to account for the relationship between performance of materials and components, service life and long term serviceability and how performance and durability data may be used in assessment of long term serviceability. This is far from an easy task and in fact the paper should be considered as an invitation to discussion and to submit proposals on how the problems might be solved.

Keywords: Durability, life cycle assessment, maintenance, performance, serviceability, service life, whole life economy.

1 Introduction

Any building has to fulfil legal requirements set up in building codes as well as the requirements of its owners and users which might be a mixture of functional requirements and social and cultural standards. It is not likely that all requirements can be fulfilled completely as the often are contradicting, e.g. high technical quality and low price, therefore it is necessary to prioritise and make compromises during the design process. The building must have the potential to meet changing needs over time, both from minute to minute, e.g. responding to

Durability of Building Materials and Components 8 (Volume Three). *Edited by M.A. Lacasse and D.J. Vanier*. Published in 1999 by NRC Research Press, Ottawa ON K1A 0R6, Canada. ISBN 0-660-17742-0

changes in weather, from day to day, e.g. changes in working patterns, space use and equipment, and from time to time, e.g. changes in occupants organisational structure and even function.

Serviceability of a building can be defined on basis of the above. The building shall at any time in its service life provide the required performance for the users. Performance seen in the broad sense that legal requirements shall be fulfilled and that functions and activities shall be supported. In the same way users should be considered as everybody with an interest in the building i.e. owners, administrators, end users, maintenance personnel etc. Serviceability may then be seen as a complicated puzzle taking into account health and safety problems, energy saving measures, life cycle analysis (LCA), whole life economy, user demands, user wishes, service life etc.

1.1 The purpose of this paper

This paper should be seen as an attempt to:

- account for the relationship between performance of materials and components, service life and long term serviceability.
- account for the use of performance and durability data in assessment of long term serviceability.

As little information is available on this subject the paper should most of all be considered as an invitation to discussion which means that al contributions which could advance the current stage are very welcome.

1.2 Performance of buildings

When dealing with prediction of service life or assessment of long term serviceability, it is a prerequisite that the building as well as its parts has a satisfactory performance. It is without interest to discuss service life if it is not first ensured that the building will function properly under its intended in-use conditions, i.e. serve as and when required Performance and long term service are therefore closely related and it is impossible to talk in depth about the one without mentioning the other.

For quite some years international co-operation on the performance approach in building has taken place in CIB commission W60. The work has to a large extent focused on the performance of building materials and components even though other problems have been dealt with as well. A number of publications have been issued by the commission including CIB report 64 Working with the Performance Approach (The Performance Approach in Building, 1982). The publication gives the basis for a methodology to be used in listing performance properties and criteria for building materials and components.

When it comes to performance of an entire building it may be seen partly as a combination of sub-performances of the materials and components of the building partly as the performance of the space, the rooms, types of rooms etc. which constitute the building

The performance of a building may in other words be subdivided into performance of (beholds)

- materials
- components
- rooms
- types of rooms
- etc.

Whatever the sub-division the overall goal is to fulfil the requirements of the user of the building, i.e. the end user, the owner/administrator, the maintenance personnel, the cleaning personnel or exterior service people making service, repair or retrofitting on the building. It is therefore quite obvious that the satisfactory performance of building materials and components is a necessary condition only - but it is not sufficient to guarantee the performance of the entire building which is far more complex.

It may be practical during the design process to divide the performance af the building into

- "Building related performance" which is connected to the building and is more or less permanent, e.g. the performance of the load bearing structure, the basement etc. and
- "Functional performance", which also is connected to the building but may change with changes in use, e.g. the requirements to fire resistance of partitions walls.

1.3 Prediction of service life

Service life is defined as the time during which at least the essential performance properties are maintained at a satisfactory level.

Big interest has been paid to this subject resulting in international co-operation regarding prediction of service life in joint CIB/RILEM committees on "Prediction of Service Life" and "Design for durability" respectively. A recommendation on the prediction of service life of building products has been issued by RILEM, (Masters, L.W. and Brandt, E., 1989). This recommendation is a methodology on how service life can be predicted using different paths. It is currently under standardisation as it is part of the draft ISO standard "Buildings – service life planning". (Draft ISO 15686-1, Part 1, 1998).

2 Changes in requirements over time

The society is characterised by rapid changes in life style, use patterns etc. which also results in changes in the requirements to buildings and infrastructure, i.e. performance requirements are dynamic and are changing with time. Ideally a building should be able to adapt to any new requirements from the users when it occur, but it is hardly likely to take place in practice. More pragmatic a building should be made flexible to allow future adjustments to anticipated and/or likely changes. Changes in the function /use of a building might lead to changes in the exposure of materials and components under use, e.g. more wear or higher temperature, which is reflected in changed requirements to materials, components and maintenance.

Assessment of future changes in society, development of technology etc. is far from easy. For example changes in use is more often expected to be improvements due to increased demands of the user, e.g. as regards installations for support of IT-technology or better thermal insulation. The question is, are we able to predict the future for the building. Are there any means available to help predict if and when an old warehouse is transformed into a block of flats? And are there any means of predicting a change in use patterns for example as experienced with the use of bathrooms where earlier times once-a-week bath in a bath-tub has been substituted by a once or twice per day shower, resulting in far harsher influence on the construction than earlier?

Also it should be remembered that a change is not always an increase but might also mean a decrease e.g. demand for less space due to fewer staff or down prioritising of the building e.g. from head quarters to ordinary office building.

Changes with time also includes a desire to use new technology as it becomes available and affordable (who wants to buy a car without ABS brakes and airbags?).

An example of development in materials is the changes in low slope roofing membranes, where a continued development has taken place over several decades changing from oxidised bitumen to APP or SBS modified bitumens and new materials like PVC or EPDM. Also new technology as radio, television, computers etc has led to increased requirements to more wiring/electrical power in the houses over the years. For some products the development is quite steady whereas for others developments are in jumps. For example windows glazing originally was single layer with a rather inferior performance as regards heat transmission. At some time double layer glasses became common and was eventually included as a requirement in the building code (at least in some countries). Now new technology has become available with low energy glass, and in Denmark this has almost immediately resulted in new requirements in the building codes.

Experience shows that for economical reasons existing products are only seldom exchanged with new with a better performance unless there are other reason, e.g. legal requirements, that makes it necessary or beneficial.

3 The important factors for long term serviceability

3.1 Performance

The most important factor for serviceability is that the functional performance of the building is fulfilled at any time. Performance may be considered the tool used to set requirements and to assess whether they are fulfilled. It is proposed that to ensure serviceability the requirements are set based on the latest developments in knowledge. If possible the requirements should include requirements taking into account any predicted changes in, e.g. the future use, the future legal requirements or increased user demands. If this is not possible the building should at least be flexible, i.e. as far as possible be prepared for future changes in requirements which might be reflected into changes in the building. The layout of the building has a great influence in this connection. For example will clear and well arranged plan layouts and a sufficient number of ducts for pipes and wires designed for future expansion and renewal improve the possibility to adjust the performance of the building to future demands.

In some cases changes in the building are rather likely to occur within a short span of years whereas for others major and affordable changes are rare or none existent. As a rough rule of thumb the following intervals are proposed:

• department stores	every 3-5 years
• offices	every 10-20 years
• dwellings	every 20-50 years

3.2 Service life

The service life is another key factor for serviceability. Normally service life is considered to be the lifetime of materials and components but there is no reason why this concept should not be used also for rooms, types of rooms, buildings etc.

For materials and components knowledge about service life can be used to:

- assess intervals between maintenance
- calculate whole life economy for alternative solutions
- perform life cycle analysis of old and new products

For rooms, buildings etc. no tools exist but an assessment of the expected service life should never the less be performed based on the latest knowledge within the area and the expectations to the future.

Prediction of service life is difficult for many reasons one of them being that in some types of buildings service life is often terminated for other reasons than technical. This might be due to wish of another appearence, which for example often is the reason for change of carpets, or due to change of use, for example a partition wall in an office building which becomes obsolete when changing to an open plan office. The service life of a building may be concidered to consist of a "Building related life" and a "Functional related life". "The Building related life" is connected to the technical side of the building and depends on the building components and materials lifetime. "The Functional related life depends on the use of the building. For example will new and changed requirements for the use of a building result in shorter functional lifetime for materials and components which still has a building related lifetime e.g. change off carpets and tiles due to fashion or other use off the rooms.

3.3 Capital costs versus running costs

As the economic means are usually not unlimited serviceability includes an assessment of the balance between the desired performance and the price to obtain it. It is therefore worthwhile to consider where the money are used – capital costs versus running costs, even though it is not the main topic of this paper.

From Danish investigations it is known that the biggest savings in capital costs as well as running costs can be achieved by choosing the optimal area depending on the number of persons and the functions to be carried out (goes for office buildings and similar), and by reducing the area/volume ratio as this implies energy savings and minimising of the exterior envelope of the building.

It is proposed to take advantage of the tools developed for use with the performance concept in building when assessing the need for space. The assessment should be based on an analysis of the intended use and sufficient space should be provided for that purpose. Sufficient in this connection means not to little as it might jeopardise the function/work and not to much as it might increase the cost. Decisions on a "reserve" for future expansions is political and should be taken by the owner/administrator as future uses might be a decrease in the space demand as well as an increase.

3.3 Running costs

The running costs are dependent on a number of factors for example

- geographical position, e.g. as regards the demand heating and/or cooling
- political interest, e.g. as regards taxes to regulate the energy consumption
- cultural differences, e.g. differences in the way of using the buildings and its surroundings

The running costs may be sub-divided into the following categories which are normally considered the most important from an economical point of view:

- energy costs
- cleaning costs
- maintenance, i.e. repair works, refurbishment etc.
- supply, i.e. water, electricity etc.

These cost can to a large extent be influenced and this is most effectively done in the early brief or design stages. At later stages the possibility for influence will drop rapidly.

Whereas very effective tools exists as regards the possibilities of assessing the energy demand of buildings very little exist as regards cleaning and maintenance. For these two subjects the designer first of all has to rely on feedback from practice. However, some general rules of thumb are available.

As regards cleaning the designer should consider how cleaning is going to take place and which requirements this implies. Some examples are:

- sufficient space shall be available for transport of cleaning equipment including wide doors, lifts, ramps (instead of stairs) etc.
- the design shall as far as possible allow for cleaning using machines.
- rooms for cleaning shall be available for storing of detergents etc. and shall include tap and sink and high power voltage for machinery.
- the demand for ladders, lifts etc to be able to polish windows, clean lamps etc.
- assessment of floor and wall surfaces especially in high wear areas.
- bathrooms and toilets with easy-to-clean surfaces and wall hung toilets.

As regards maintenance the designer should remember that some materials and components are impossible to access when the building is finished and maintenance consequently impossible. Especially in situations like these and where maintenance can be foreseen to be performed only very rarely, great care should be taken in choosing materials with a long record of serving well with limited or no maintenance. Especially care schould be taken to avoid use of materials or components if failure could increase the risk of further damage to the building, e.g. fungus and dry rot in a roof construction due to an inferior roof cladding. Under all circumstances it should be considered how maintenance and minor refurbishment works are going to take place and which requirements this implies. Some examples on how things might be improved are:

- things shall be easy to access – sufficient room in crawl spaces, removable coverings etc.
- things shall be easy to repair or replace.

- as far as possible "parallel lives" or "parallel maintenance intervals" should be chosen, i.e. neighbouring elements should have the same maintenance or replacement intervals in order to avoid great expenses of replacing well functioning elements due to failure of others, e.g. replacing a roof covering due to the need of replacement of the roof tile underlay.

4 How can life time serviceability be assured

In practice life time serviceability can not be assured but some precautions might be taken to improve the likelihood of a good serviceability during the entire service life.

It is the performance of the comprehensive product that counts and this is not necessarily related to materials or components but the good performance of the materials is often a prerequisite for the performance of the comprehensive product. Therefore:

a satisfactory performance of building materials and components are crucial to the serviceability of the building. Available data on performance of the used materials should therefore be exploited as far as possible.

As regards service life, deterioration does not necessarily affect the performance, i.e. a deterioration of a material may well take place without immediate loss in performance of the building. However, in the long run the durability of materials and components is often a prerequisite for the performance of the material and consequently of the comprehensive product. Therefore:

a satisfactory durability of building materials and components are crucial to the serviceability of the building. Available data on service life of the used materials should therefore be exploited as far as possible.

Parallel life times or maintenance intervals should be used as far as possible.

Performance requirements are dynamic, i.e. they may be regulated by legislation and by corporate or professional norms or changed due to user demands. As this sort of changes are often very difficult to predict it is proposed:

to set up requirements primarily based on the newest knowledge and as far as possible taking into account any foreseeable or likely change in future requirements. Different solutions might be possible and it is proposed to make a comparison between the different scenarios including whole life economy, sustainability, indoor air quality, energy consumption etc.

The costs are decisive for most decisions taken and attention should therefore be paid to influence the capital cost as well as the running costs. This implies:

the building should be designed with the optimal area per person, and by reducing the area/volume ratio as this implies energy savings and minimising of the exterior envelope of the building.

Cleaning, maintenance, repair and refurbishment should be taken into account at the early brief or design stages in order to facilitate access, use materials suited for the type of use etc.

5 Conclusions

Very little exploration on the subject of this paper has taken place and much needs to be done. The paper should be considered as a very first attempt to review some of the problems that are faced when discussing life time serviceability. The paper should also be considered a platform for discussion and any contribution to a discussion will be very much appreciated.

Finally it should be noted that this paper is about new building and in reality the biggest challenge is to find tools for future refurbishment of the big stock of existing buildings.

6 References

Working with the Performance Approach in Building, (1982), CIB report 64, International Council for Building Research Studies and Documentation, CIB, Rotterdam.

Masters, L.W. and Brandt, E. (1989) Systematic Methodology for Service Life Prediction of Building Materials and Components, *Matériaux et Constructions/Materials and Structures.*

Draft ISO standard 15686-1, "Buildings – service life planning", Part 1, 1998.

Masters, L.W. (ed.) (1986), *Prediction of Service Life of Building Materials and Components,* CIB Publication 96, International Council for Building Research Studies and Documentation, (CIB), Rotterdam.

Masters L.W. and Brandt E. (1987), Prediction of service life of building materials and components, *Matériaux et Constructions/Materials and Structures..*

Brandt. E. (1998), The interrelationship between the performance and the service life of building products, Proceedings, CIB World Congress, Stockholm, 1998.

173 PERFORMANCE CONCEPT IN THE PROCUREMENT OF DURABILITY AND SERVICEABILITY OF BUILDINGS

G.K.I. Ang[1] and D.P. Wyatt[2]

[1]Government Building Agency, The Hague, The Netherlands, [2]University of Brighton, UK

Abstract

In researching and preparing this paper it has seemed with an increasingly clarity that there is a case for adopting a performance scope approach in order to maximise upon the degree of freedom necessary in the early stages of the brief and design-concept if durability and serviceability of buildings is to be secured. In doing so permitting a fuller review of the building's own life cycle and, on a larger scale, the asset management of a building portfolio. The usefulness of a building, in terms of functional and economical performance, depends on its ability to support the primary activities of the owner organisation in adding value to their products and services. More specifically the building's configuration and space quality will need to respond to the way the activities are linked within the owners value chains and their associated embodied energy can fit within a broader base target set on a break down basis. Hot issues in the environmental agenda system, i.e. the life circuit of the building, its whole life costs and material life cycle appraisal may not fit comfortably in the current models for the building process and its project-management. Perhaps by using an integral performance approach in procurement this could change if only because the whole life or parts of the life can be embraced in the pre-briefing or briefing stages to suit.

Keywords: Service life, life cycle assessment, real estate management, durability, serviceability, performance based procurement, design agenda, maintenance strategies.

Durability of Building Materials and Components 8 (Volume Three). *Edited by M.A. Lacasse and D.J. Vanier*. Published in 1999 by NRC Research Press, Ottawa ON K1A 0R6, Canada. ISBN 0-660-17742-0

1 Introduction

Serviceability and durability of buildings should be the result of properly planned service life and life design management, focused on the building as an economic and sustainable housing solution for the desired purposes over time. Today's economy forces the business to mobility and flexibility in order to survive by tackling the unpredictable future of ever-speeding shifts in the (global) market. As a consequence the buildings serviceability and durability will be considered increasingly as a business resource, next to human talents, capital, technology and information. This will lead to a fuller review of the buildings own life cycle and, on a larger scale, the asset management of a real estate portfolio. It also introduces a more conscious view on maintenance strategies, as priorities will be set on other aspects and performances than on the technical quality only.

Feedback from use, i.e. post occupancy evaluation, should be stimulated as it provides criteria for a more conscious design process for durability and serviceability, which actually is the key issue to building sustainability. When it comes to procurement, these performance issues might not fit comfortably in the current models for the building process - and project- management, because for instance there is a problem in directly matching these issues with technical building data and investment costs. An integral performance approach in the early stages of the brief and design-concept is recommended because such an approach provides the methodology how to match technical building quality with functional (fitness-for-use) quality in terms of the price / performance ratio.

This paper introduces an approach towards a more conscious procurement of durability and serviceability of buildings by looking at the issue through the performance scope. First service life and serviceability is defined briefly. Then strategies for securing serviceability are indicated briefly and finally conclusions are drawn in terms of maintenance strategies, the importance of the design agenda and the adoption of the performance approach in procurement.

2 Service life

The adoption of service life planning and life design management may be seen as the key in the LCA approach, one underpinned by a service life which is itself defined as:

> "*That period of time at which the building, parts or elements, components and services of a building reach a state of performance which is unacceptable*" (ISO 15686 Part 1 1998).

In turn this service life should be linked fully with both the supply chain management and its life cycle assessment so that one manages the life cycle within a strategy to "husband" the inbound supply chain for economic - cost benefit as landfill charges rise. At the same time securing space and functional life quality, fit for the purposes and the life performances required.

In the construction market buildings are still largely seen as an end in itself instead of being considered to serve owners and users. Whilst the respective range of materials and products laminated, form its construction, the client or building owner concerns may well be the quality of serviceability of their building portfolio or stock. The usefulness of a building, in terms of technical quality, functional quality and economical quality, therefore depends on its ability to support the primary activities of the owner organisation in adding value to their products and services.

The average client will see a building primarily as a necessity to support the primary functions of his organisation; it has to be able to adapt to changes in this organisation in order to allow anticipation on shifts and competition in the market. Service life should therefore cover the demands of building serviceability in a more explicit manner within the definition of the ISO 15686 Part 1 1998.

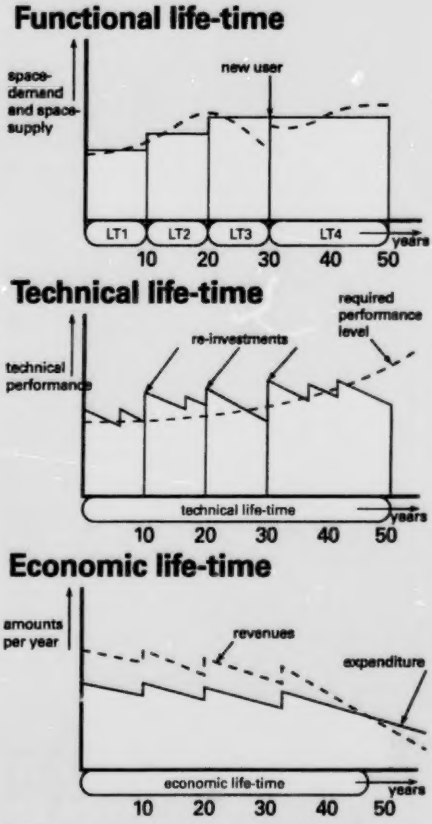
It is therefore suggested to analyse the relation between functional, technical and economical service-life of a building. (de Jonge 1994). A schematic of the various types of service life is provided in Figure 1 below. The functional life of a building is the time span within which an organisation can operate without major changes in the building. The top graph shows the growth and decline of one user organisation. Major adaptations have been made two times within 30 years.

Related to the top graph the second graph shows the technical performances required. The technical life is the time span within which the building meets the technical performance criteria in a given maintenance strategy. The required performance does not only depend on functional fitness-for-use requirements but also heavily on regulations. Safety regulations force buildings into long-lasting products. At the points in time that the functional performance of the building is adjusted (years 10, 20, 30) reinvestments are done. The bottom graph shows the economical service-life of the building, that is the time span within which the building meets the return - on - investment criteria of the owner.

Each time when functional and technical adjustments in the building performance are made the expenditure and revenue figures do change. In the past decades the technical service lifetime was approximately 50 years for structure and shell. Today it occurs that office buildings with an age of 12-15 years are demolished to give way to new construction. The average functional service life is becoming shorter and forces a return-on-investment to come in quicker.

Within this context the reduction of the technical service life is no option because this would in fact be destruction of capital investment. Generally the fiscal systems do not allow the speed of writing off for depreciation that goes with the functional wear of buildings.

The options can merely be found in technical solutions that are based upon the principle of "loose fit", indicating that parts of the building can be replaced easily. As a consequence, structure and shell should be designed less function-specific in order to allow changes in serviceability performances.



Functional life-time

Technical life-time

Economic life-time

space-demand and space-supply
new user
LT1
LT2
LT3
LT4
years
10
20
30
40
50
technical performance
re-investments
required performance level
technical life-time
years
10
20
30
40
50
amounts per year
revenues
expenditure
economic life-time
years
10
20
30
40
50

© Government Buildings Agency, Prof. ir. H. de Jonge

Fig. 1: Functional technical and economic service life of facilities (de Jonge 1994)

3 Serviceability

Serviceability may be used to describe a condition state or reflect the quality of building life that may include durability as a sub-system. Serviceability may be used holistically to describe the quality or the ease with which a building can be serviced or maintained (Wyatt 1998). The serviceability of a facility, such as a workplace or a home, is its capability to perform as and when required, supporting the activities and functions of users and owners. For each type of functional capability, there exists a different serviceability profile (Davis 1998).

Hence, benchmarking serviceability may be useful in planning how to move a building stock to a better condition level especially within a culture of restricted funding or in developing a pathway to a sustainable building.

Nevertheless it should be kept in mind that even if a building is potentially sound and in a "reasonable state of repair" (i.e. serviceable) but unwanted either by the building owner, or rejected by tenants, it may still by default be deemed "unfit". In other instances, the potential value of a site or area for re-development may be such that this will hasten the demise of a perfectly serviceable building or cause a number of sound buildings in that area to be abandoned or become "obsolete".

In fact the physical environment has always been the print of economic, political and cultural aspects of a society. Growth and decline has become visible in the structure of many cities. Today's economy is one of speed and global shifts and the unpredictable future demands for mobility and flexibility. Most of the industrialised countries in the Western Hemisphere are growing into post-industrial economies with an emphasis on product development, trade, services and distribution. Therefore the problems arising from building alterations necessary to meet changing organisational needs by any of their owners or tenants over the building's life time must be understood in a strategy to secure serviceability in the management of real estate.

In the management of real estate one can distinguish two main focus-points:

- Portfolio-management where the optimising criterion generally is return on investment, because the real estate portfolio is considered to be a source of income.
- Facilities-management, where real estate is considered to be a means of supporting the business process.

The optimising criterion is the contribution to the overall results of the company. We can observe that under today's market pressure these two focus-points tend to meet each other (de Jonge 1994).

The cost sheet of the customer in an administrative sector (offices) shows (Table 1) that the facilities will cost on average approximately $US 12,000 per year. Considering an average salary costs of $US 37,000 per year in this sector it becomes obvious that 25% of the total costs per year is directly related to facilities (de Jong 1994). The difference between minimum and maximum shows a potential gain when better "workplace-management" for the user can be achieved (facilities-management).

For the real estate owners this becomes a vital issue because of today's periods of oversupply. It forces the building suppliers to get involved into specific users interests in order to survive in today's "buyer's market" (portfolio-management). These mechanisms do form the basis for securing serviceability within real estate management and for setting maintenance strategies accordingly. The feedback from post-occupancy-evaluation will provide mutual benefit for demand and supply within this context. Proper implementation of such a feedback into the design agenda of new-built or re-built accommodation will therefore facilitate a more conscious procurement, likewise securing the durability and serviceability of buildings.

Table 1: Range of facilities operational costs

COSTS OF:	COSTS US $/YEAR)	MIN	MAX	AVERAGE %
Capital	2450	3850	3250	32.5
Energy	200	600	412	4.1
Maintenance	250	520	400	4.0
Cleaning	210	280	250	2.5
Security	375	550	475	4.8
Catering	650	1075	750	7.5
Management	900	1750	1300	1.0
Reproduction + Post	400	1500	950	9.5
Stationary	250	625	400	4.0
Fittings	200	700	475	4.8
Communications	200	700	450	4.5
Data-services	500	1250	875	8.8
Total	6585	13400	9988	100.0
Total incl. tax.	7800	15879	11835	

4 Maintenance strategies

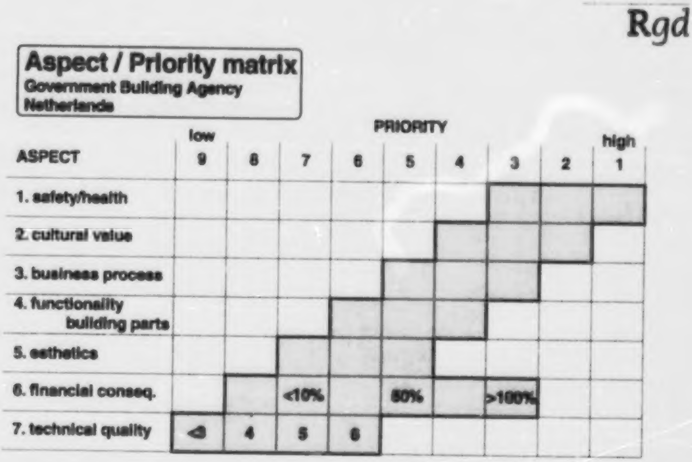
Building maintenance seems often to be an autonomous issue, based upon the maintenance expectation of building parts and materials over time (bottom-up approach). From the serviceability point of view however, there is a need for linking the maintenance strategy (based upon the technical service life of buildings) with the real estate and business strategies (based upon the economical and functional service life) as to provide a "just-in-time and fit-for-purpose" maintenance effort (top-down approach). The suggested maintenance strategy is the result of a properly controlled confrontation between the bottom-up and top-down approach by using the following control parameters: the state of repair; aspect/priority matrix. Each in turn will be briefly consider below.

4.1 Determining the state of repair (Vyverberg 1995)

The key parameters for the state of repair are the shortcomings of the building parts in the categories functional, technical, esthetical aspects and "basic quality". Basic quality is determined by the measured state of repair of a building part compared to the original quality at the moment of building hand-over/delivery.

4.2 Aspect/priority matrix

The Dutch Government Building Agency (GBA) has developed a so-called Aspect/Priority Matrix in co-operation with Damen Consultants in Rotterdam, Netherlands. The aim is to determine priorities in maintenance efforts in relation to functional and economical aspects such as safety/health, aesthetics, use value/functionality, indoor climate, financial consequences over time and technical quality. The GBA applies a 9-points score-list for the priorities, starting with the highest priority (1) and ending up in the lowest priority (9). The figure below shows how the GBA uses the matrix for the maintenance-activities scheduled for the real estate stock on their account.



Rgd

Aspect / Priority matrix
Government Building Agency
Netherlands

	PRIORITY								
	low								high
ASPECT	9	8	7	6	5	4	3	2	1
1. safety/health							▨	▨	▨
2. cultural value						▨	▨	▨	
3. business process					▨	▨	▨		
4. functionality building parts				▨	▨	▨			
5. esthetics			▨	▨	▨				
6. financial conseq.		▨	<10%		50%	▨	>100%		
7. technical quality	<3	4	5	6					

Fig. 2: Maintenance activities schedule based on functional requirement-priority matrix (Vyverberg 1995)

4.3 Key properties (Brandt 1998)

Ideally all properties of building parts shall be maintained at a satisfactory level for the prescribed lifetime but this is very difficult and expensive to achieve. A pragmatic solution is to work on a lower basic level and look at the most important properties (key-properties) for the product in situ. It is suggested to use the same approach when dealing with assessment of durability. In ageing tests these key properties can be tested at intervals as to indicate the extent to which minimum values are being approached.

When it comes to decisions about budgets for maintenance there is a certain interdependence with housing scenario's, i.e. Consolidation, Extension, Renovation, Re-use, Decommissioning or Demolishing. The majority of buildings in a real estate stock likely are in the consolidation scenario and a "normal" maintenance budget will be needed. But in the case of Renovation and Extension, renewal of installations and fittings should influence the "normal" maintenance schedule as to avoid double investments. In the case of Decommissioning or Demolition, there will be no need to fulfil the entire maintenance schedule and the maintenance budget can be altered accordingly.

4.4 Interrelation of the building shape and maintenance budget (Vyverberg 1995)

The building shape, i.e. flat roof or sloped roof, shell/content-ratio, uniformity or diversity in building parts etc., and the application of materials do influence the budget needed for maintenance in a considerable way. A complex-shaped building will definitely demand for more maintenance budget than an "average" building and for that reason a shape-material index is introduced in order to facilitate the alteration of maintenance budget accordingly.

Traditionally, building management focuses on minimising short-term maintenance costs. Currently a change can be observed towards optimising maintenance in relation to organisational goals and means in the middle and long term perspectives. The maintenance sector shows a transition from technical aspects to functional aspects.

The "why" of building maintenance is becoming a focal point: which objectives does an organisation have for its buildings, and which are the budgets to be made available for realising those objectives. Maintenance is seen as one of the means to manage real estate, next to, for instance, buying, selling and refurbishment. (Hermans 1998).

Many of us do bear in mind some of the shortcomings that may be found in an existing building portfolio or stock which inevitably have cost consequences though not always quantified, e.g. finishes failures, lifts out of service, poor air-conditioning or an environmental control malfunction. Many of these issues may be seen as serviceability problems, which are perhaps more clearly observed where poor heating controls exist or excessive cracking is experienced or unexpected movements take place, perhaps due to climatic extremes.

Due to financial constraints, such maintenance needs may often gain low priority or in dealing with such problems a conflict of interest may arise. Therefore it is suggested that there is a need to promote a procurement practise that secures a sustainable and perhaps more importantly a whole life construction that gives a degree of flexibility, the basis of affordability, fitness for purpose within a legal punitive system; a design life. To this end an attempt is made to structure those decision processes to reflect and incorporate the conflicting purposes of legitimate interest groups towards more imaginative, yet environmentally responsive, design and life care solutions, that accords with a sustainable practice. Central to this view may be that argument that there is a need to scope a design agenda.

5 The design agenda

It is against the above that there is believed to be a need to re-scope the design agenda so that the brief can contribute more effectively to the front end to ensure product life quality. Perhaps against some established or understood performance base or benchmark; one which also includes an environmental life cycle assessment.

The design agenda audit (Cooper and Press 1995) is a common meeting point or ground and should enable a richness to new developments and blend the best of new technologies as well as moving to a new form of building and the place for signature architecture.

In theory then all decision points can be seen in terms of data collecting points (and potential measurement points) that may enable one to determine the effectiveness of the product or procurement process under consideration. Such an approach enables one to examine what the impediments are to achieving a higher level of customer service and satisfaction without loosing sight of relationships or being swamped by detail (Ang 1996).

The main issue then is to deliver the desired performance rather than to describe how to achieve it. As a matter of fact the skills and know-how of the design/build process really belong to the supply side rather than to the client side. Therefore it would be more sensible for the client to focus on their output-performance rather than on input-prescription.

In consequence, the strategic relevance of the performance approach does move the whole building product life frame forward, perhaps even encouraging or securing the transfer of bench marking and total quality management to the performance measurement system. Further, because the building is itself a business asset, the client-owner should define and continue to refine their fitness-for-use criteria rather than in technical descriptions/solutions (Ang 1995).

Thus, mobilising towards fitness-for-use seems to be an early indication of the direction being headed for in the current and future agenda for design, but it introduces a demand and supply matching problem between user-requirements and building features (Ang and Wyatt 1998).

In favour of an approach towards a more conscious procurement of durability and serviceability of buildings a performance auditing would permit a form of product bench marking that a client or building or portfolio organisation could draw upon with benefit. As time moves on one might come to see the performance model as a common currency that would become the linking of the supply chain, space domain and life assessment whether for a cost/quality domain or environmental assessment.

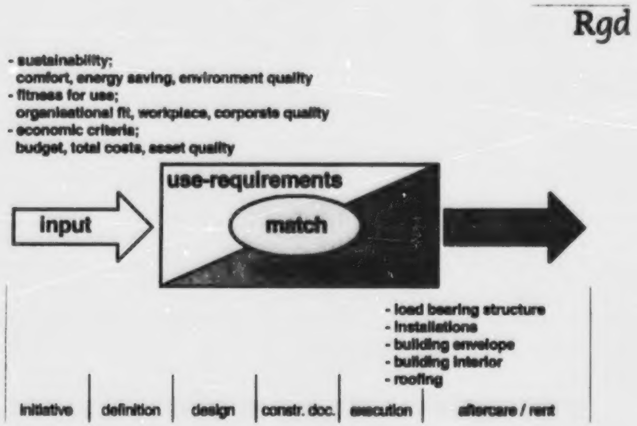

Rgd
- sustainability;
comfort, energy saving, environment quality
- fitness for use;
organisational fit, workplace, corporate quality
- economic criteria;
budget, total costs, asset quality
use-requirements
input
match
- load bearing structure
- installations
- building envelope
- building interior
- roofing
initiative
definition
design
constr. doc.
execution
aftercare / rent

Fig. 3: Fitness-for-use design agenda: matching building features to use-requirements

Auditing and monitoring the design/build process should therefore start in the early phase of performance-based brief and conceptual design sketch as shown below in Figure 3 (Ang 1998). It is here that applied research based upon post-occupancy-evaluation should be carried out in order to provide:

- A data bank providing for information and references of previous projects based upon feedback from use, including maintenance and design experiences and skills audit.
- Typology studies providing knowledge and tools how to relate between sustainability, use pattern, economical/functional life span and the potential value of design concepts as to create best conditions for a successful match between demand and supply.
- Environmental calculation methods in brief, design and build as a performance-based decision support model (Dewever 1998).

When designing a building the most likely reason for replacement of the individual components should be assessed. Then the moment when replacement will take place should be estimated, based on practical experiences with similar components in other situations. This actual practice-based period of use should therefore be the starting point for environmental calculations (Hermans 1998).

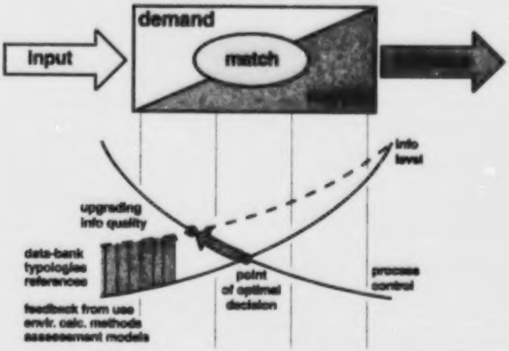

demand
input
match
info level
upgrading info quality
data-bank typologies references
feedback from use envir. calc. methods assessment models
point of optimal decision
process control

Fig. 4: Performance based brief and conceptual design sketch (Ang 1998)

Assessment models for monitoring the design/build process are at this time not in a form that expedites whole life procurement assessments to deliver a sustainable total product quality. One would need to establish and use an understood method or model including options as to secure the necessary product and project skills. It is suggested that the varying basis of the gate keeper model (Wyatt 1995) needs to be brought into an expert system with agreed product and project protocols through the procurement cycle (Painting and Wyatt 1995) and the operational life from cradle to grave.

6 Conclusions

Buildings do involve large capital outlay in clients organisations in the expectation that this outlay will be recovered from the value added output which the building, in combination with other capital assets, help to produce.

In consequence, today building configurations and space quality should respond to the way owners and occupiers perceive value and usefulness in a period of considerable change, where environmental management may change the way all business will operate.

Therefore it is suggested to develop an appropriate procurement system that facilitates a more conscious procurement of durability and serviceability by looking through the performance-scope. Equally a better understanding of the design agenda and the importance of life briefing could be underpinned by accepting the focus of a performance scope in future design agenda's.

7 References

Ang, G.K.I. (1995), "Performance Tendering a Threat for the Architect", The International Journal of Architectural Management, Practice and Research Vol. 10, pp. 71-795.

Ang, G.K.I. (1996), "The Role of Performance Specifications in Project Initiation", CIB/W60 keynote 3rd International Symposium Tel Aviv, Israel.

Ang, G.K.I. (1998), "Sustainable Design/Build and the Performance Concept", Paper 14th CIB World Congress Sweden 1998, Government Building Agency Netherlands.

Ang, G.K.I. and Wyatt, D.P. (1998), "The Role of Performance Specifications in the Design Agenda", W96-Conference Sept. 18-19th, Brighton, UK.

Brandt, E. 1998, "The Interrelationship between the Performance and the Service Life of Building Products, Paper 14th CIB World Congress Sweden 1998, SBI Danish Building Research Institute, Horsholm Denmark.

Cooper, R. and Press, M. (1995), "The Design Agenda", Wiley Publications, UK, pp. 187 – 214.

Davis, G. (1998), Working Draft for: "Performance Standards in building-Serviceability of Facilities"- Part I: Principles ISO/TC 59/SC 3. June 15th 1998, International Centre for Facilities Ottawa, Canada.

De Jonge, H. (1994), "Change and Chance", keynote address, 3rd annual TWN Workshop, Delft University of Technology, Netherlands.

Dewever, M. (1998), "Environmental Costs, a Decision Support Model based upon Environmental Calculations for Buildings", Paper 14th CIB World Congress Sweden 1998, Government Building Agency Netherlands.

Hermans, M. (1998), "Building Performance starts at Hand-over: The importance of Life span Information", 8dbmc Conference, Vancouver, Canada, May 1999.

Painting, N.P. and Wyatt, D.P. (1995), "The Strategic Role of Design/Build in Extending the Procurement Cycle", International Congress on Construction, Singapore, SG, 7p.

Vyverberg, G. (1995), "Building Maintenance based upon Housing Policy", a Theoretical Model, Delft University of Technology, Netherlands.

Wyatt, D.P. (1995), "The Unhappy Gate Keeper", The International Journal of Architectural Management, Practice and Research No 971-79.

Wyatt, D.P. (1998), "Securing Sustainable Building and Resource Management through the role of Serviceability", Paper 8dbmc Conference Vancouver Canada 1999, University of Brighton UK.

174 LIFE CYCLE APPRAISAL OF BUILDING ELEMENTS BY MULTIPLE PERFORMANCE INDICATORS

M. Aygun

Istanbul Technical University, Istanbul, Turkey

Abstract

Functional elements constituting buildings are delegated by functional requirements, affected by agents and finally evaluated by performance requirements. These elements can be represented by conceptual object oriented product models. Work is undertaken to elaborate on the element model and subsequently to develop a method for the evaluation in terms of and comparison of the life cycle performance in terms of multiple indicators pertaining to element alternatives illustrated here by glazed building envelope systems. Components as discrete parts of any one element are intended to satisfy one or more of the functional requirements pertaining to that element. Thus the resultant overall element performance depends on the performances of individual components. Conversely, any one requirement may implicate one or more components. Appropriate performance requirements for evaluating elements are identified for each phase of the life cycle. These requirements are measured by performance indicators to which relative weights are then assigned. Component performance is evaluated in two consecutive stages. These stages employ the same procedure, but life cycle and statistical indicators are substituted respectively. Multiple statistical parameters are utilized to supplement the average utility value of that component in order to account for the deviation of indicator values. Hence a single overall indicator value is obtained that allows component performances to be in effect combined through enhanced aggregation to yield the overall element performance. Consequently the method allows the following entities to be appraised: 1. Relative component performances over the complete life cycle, 2. Relative element performances in any one phase or over the complete life cycle. This approach is demonstrated by means of an implementation on envelope systems.

Keywords: Building element, life cycle, performance appraisal, multiple indicators

Durability of Building Materials and Components 8 (Volume Three). *Edited by M.A. Lacasse and D.J. Vanier*. Published in 1999 by NRC Research Press, Ottawa ON K1A 0R6, Canada. ISBN 0-660-17742-0

1 Introduction

Contemporary building elements are assembled from a wide range of materials and components available as a result of advancing technology. These elements must satisfy the various performance requirements over their complete life cycle. At present the *a priori* arguments are the depletion of natural resources and environmental pollution. Appropriate configuration of elements contributes significantly to the resolution of these prevalent arguments beside providing satisfactory service in terms of non-environmental stipulations.

A methodical approach to the appraisal of life cycle performance for element alternatives assures identification of the most effective solutions that are also efficient in utilization of resources, the *raison d'être* being the desire for a better environment.

An overview of some recent research on this subject is presented as follows.

Vanier et al. demonstrate that product models can provide the structure needed to represent user requirements and propose a model consisting of five interrelated concepts with attributes as a complete data structure (Vanier et al. 1996). Beccali and Cellura describe a comparative evaluation of energy and environmental performances of constructional alternatives according to the Electre methodology (Beccali and Cellura 1996). Weibel presents the cumulative normalized environmental effects of building materials to allow comparative appraisal (Weibel 1996). Kohler and Klingele apply the life cycle assessment model in terms of energy and mass flow to the building as an object consisting of elements and phases (Kohler and Klingele 1996). Lounis et al. propose a stochastic model of performance using a discrete Markow chain that predicts the incremental deterioration allowing the simultaneous consideration of the time dependence and randomness of performance taking into account uncertainty and variability (Lounis et al. 1998). Haas presents the TWIN model, an environmental calculation method as performance concept based on a double layer system where the first layer quantitatively uses all available life cycle assessment results and the second qualitatively compliments the other (Haas 1998). Maggi et al. present a method to develop a functional analysis as a tool for designing new building components, initiated by a set of functional model hypothesis that describe the distribution of functions through the component structure followed by actual models (Maggi 1998). Le Teno et al. propose a framework to compile information on building products' environmental quality based on a merging of life cycle analysis and risk analysis into a semi-quantitative approach (Le Teno et al. 1998). Aygun makes a proposal for quantifying the effects of various energy and mass flow attributes of buildings on their relative environmental performance (Aygun 1998).

Herewith acknowledged is the subsidy received form the Scientific and Technical Research Council of Turkey for part of the work described below.

2 Functional element model

A conceptual model is required for incorporating building elements within the performance appraisal process. An object oriented approach is adopted in compliance with international standards of product modeling, enabling parametric description of elements. Consequently the principles of inheritance and encapsulation are observed following the hierarchical order of building, element, component and material. The object hierarchy allows any sub-types (descendants) derived from the main types (ancestors) to inherit the embedded attributes while possessing their idiosyncratic attributes. Instances of these objects are obtained when actual values are assigned to these attributes as independent variables of element design.

The functional element (FE) *cum* product model is elaborated to define components and their specific attributes beside those pertaining to the entire element providing a framework for describing any element in a standard format.

The synopsis of the model description is presented below:

Element:
- Location: External (Below ground, Above ground, Partly above ground), Internal, Semi-enclosed.
- Inclination: Horizontal, Vertical, Inclined.
- Order of Components (Layers in the context of the building envelope):
  - External finish or layer (Surface characteristics)
  - Thermal insulant and Vapour barrier
  - Waterproofing
  - Core and/or Carrier
  - Supplementary Layer (e.g. filter or drain sheet)

Component:
- Geometry (Form, Dimension, Position)
- Intra- / Inter-component Joints
- Material (Chemical, Physical and Biological description, Surface properties)
- Structural (Self-supporting, Supporting other component of same element / other element)
- Restraint/Support/ Attachment / Fixing

Functional requirements (FR) are the stipulations that are anticipated to be complied with by the functional element consisting of various functional components (FC) as discrete physical parts that are emphasized in this paper. Relative weights may be ascribed to functional requirements for reflecting their significance or importance. Each requirement *per se* implicates one or more functional components (FC), each of which is allocated to any number of functional requirements. Some of the latter, e.g. embodied energy, eco-toxicity, pertain to the entire element, rather than to only some components.

Component performances are appraised by performance requirements (PR) that express to what degree the pertinent functional requirements are fulfilled. Performance indicators (PI) are applied for measurement (Vanier et al. 1996). For instance, in the context of ecological performances, which have become the present *genius loci*, the indicators may be either medium oriented, e.g. air, water, materials and fuel, or effect oriented, e.g. ozone depletion, nutrification and acidification potentials. Since more than one component can be associated with any one performance requirement, the values of performance indicators obtained from the respective components need to be combined for appraising each performance requirement. The relationships between functional requirements, components and performance requirements as depicted in Fig. 1 can be extended to cover the entire building object. These entities can also be defined by means of a three dimensional interaction matrix.

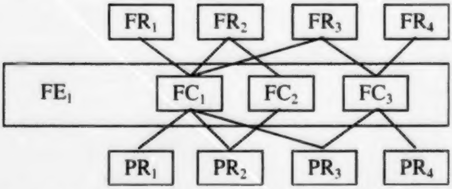


Fig. 1: Conceptual model of relationships for functional elements

The adjacencies between components, i.e. the inter-component contacts are also specified in the model. Each component is connected to at least one other inside or outside that element, as indicated by an adjacency matrix. Since there is inevitably a connection to a component of another element, the diagram extends laterally to include all connected elements, proliferating eventually to cover the entire building. Within the scope of this paper the subject matter is confined to a single element as an *laissez-faire* entity. There are two alternative notations below for the object oriented element model.

Deductive
- Element
  - Attributes
  - Function
    - Weight
    - Indicators
    - Component
      - Attributes
      - Links

Inductive
- Component
  - Attributes
  - Links
- Functions
  - Weight
  - Indicators
  - Component
- Element
  - Attributes
  - Functions

3 Life Cycle Assessment

For the purpose of life cycle assessment the conceptual element model described previously is integrated with the consecutive phases as transient element states, i.e. manufacture, construction, occupancy including repair and maintenance, refurbishment and demolition. Consequently another domain is introduced to the model which already contains the element, function and component domains. At least one or more indicators are applicable to any of the phases. While some of the related indicators in any given phase may be in accordance with each other, others may be in conflict. These relationships between indicators may also be expressed in a triangular interaction matrix. Furthermore, some of the applicable indicators may be the same at a number or all of the phases, others are specific to single phases.

Any given pair of the domains can be investigated by each implementation of the evaluation procedure based on aggregation of indicator values over the domains. This *modus operandi* therefore allows the inter- and intra domain effects of the specified element and component attributes to be explored. The procedure is accomplished in three consecutive stages (Table 1).

Stage 1: The actual indicator values (I) are ascertained for each element alternative (E) included at each life cycle phase (P). Subsequently since the indicators mostly have different dimensions, these values are standardized prior to converting them to weighted utility values.

Stage 2: The previous values are aggregated to obtain a single parameter for each phase of all element alternatives and presented in tabular form.

Stage 3: The overall utility values of elements and phases can be determined and rank-ordered as a result of row and/or column aggregation of the values obtained in the table of the penultimate stage.

Table 1: Consecutive stages of evaluation

Stage 1

	P_1			P_2			...
	I_1	I_2	...	I_1	I_2	...	
E_1							
E_2							
...							

→

Stage 2

	P_1	P_2	...
E_1			
E_2			
...			

→

Stage 3

P_1	P_2	...
E_1	E_2	...

4 Enhanced Aggregation

Each stage of the life cycle assessment repeats the same method of aggregation consisting of two consecutive parts deploying the same process into which the sets of life cycle and statistical indicators are substituted respectively.

In the first part, before the actual evaluation is undertaken, the values of each indicator are standardized to obtain non-dimensional relative values. Then utility functions and relative indicator weights are applied as required.

In the second part, the conventional aggregation process is enhanced by considering the supplementary statistical parameters of standard deviation and coefficient of variation beside the mean for any array of relative values. Thus the distribution of indicator values for each alternative is accounted for. Subsequently standardization is re-applied to all three statistical parameter values, yielding a single overall performance indicator for that set of values allowing element alternatives to be rank-ordered.

5 Implementation

The proposed method is demonstrated by means of an implementation on a set of 15 generic alternatives (E_1-E_{15}) of an hypothetical glazed (curtain) wall as represented by a functional element model with 12 performance indicators (I_1-I_{12}). The latter are functions of physical or chemical attributes. The assumed element under consideration is intended to act simultaneously as a barrier and filter between the external and internal environments by regulating mass and energy flows as with all other external building elements.

The shared attributes of all alternatives are defined as follows: Metal carrier frame with transoms and mullions, Double glazed units as transparent and opaque infill panels with reflective and low-E coatings, Units fixed to frame by pre-assembled metal edge profiles with structural sealant, Gaskets in site-assembled joints between metal components.

The design variables for generating viable element alternatives are confined to the specification of glass coating for the units, i.e. thickness, chemical composition, solar reflectance, absorbtance and transmittance of units. Alternatives are evaluated in terms of multiple performance indicators during the life cycle phases. Within the scope of this implementation the phases taken into account are manufacture , construction and occupancy. The pertinent indicators at each phase are presented below. The symbols, range of values and units of indicators are given in parentheses.

- Manufacture (P_1) : Energy (I_1: 3-5 kW/m^2), Waste (I_2: 1.5-3.7 kg/m^2), Cost (I_3: 125-250 ECU/m^2), Tolerance (I_4: ± 1-5%/m)
- Construction (P_2): Energy (I_5: 0.7-1.2 kW/m^2), Waste (I_6: 0.2-0.6 kg/m^2), Cost (I_7: 35-75 ECU/m^2), Tolerance (I_8: ± 2-7%/m)
- Occupancy (P_3) : Energy (I_9: 0.13-0.64 kW/m^2), Waste (I_{10}: 0.2-0.7 kg/m^2), Cost (I_{11}: 8-14 ECU/m^2), Shading coefficient (I_{13}:45-80%)

While some of the indicators are in accordance with each other, e.g. energy and waste, others are in conflict. e.g. tolerance and cost. The utility functions of the indicators are deemed to be linear and relative weights equal. The instances of the consecutive stages are described below as they have occurred.

Stage 1: Table 2 displays the actual indicator values of alternatives at each phase, providing the input data for the subsequent evaluation process. Then relative values are obtained through standardization. Utility functions and weights are applied. Stage 2: The statistical parameters for these values, i.e. arithmetic mean, standard deviation and variaton coefficient are calculated for each phase as given in Table 3. They are then converted to relative values to obtain an overall statistical performance indicator. Interim results are available upon request. Stage 3: Table 4 presents the final results that rank-order the alternatives that attain above-average utility values at each phase and over the complete life cycle respectively. Individual phases are also ranked.

6 Conclusions

The proposed evaluation method on the basis of the functional element model is intended for the use of researchers as well as professionals involved in the design, construction and management of buildings and their constituent parts. In the context of this paper alternative designs for a building element can be compared in terms of their life cycle performance. Ultimately the best overall performer, *i.e. primus inter pares*, among the viable alternatives providing a well synthesized solution in any domain under consideration can be identified. Furthermore comparative appraisal can be achieved of each phase in the element life cycle with respect to their individual relative performances. Those elements and phases construed as deficient in performance can be designated for further improvement. The method is anticipated to be subsequently extended to entire building objects.

Table 2: Actual values of performance indicators for element alternatives at each phase

Element	Manufacture				Construction				Occupancy			
	Energy (kwh/m^2)	Waste (kg/m^2)	Cost (ecu/m^2)	Toleran. (± %/m)	Energy (kwh/m^2)	Waste (kg/m^2)	Cost (ecu/m^2)	Toleran. (± %/m)	Energy (kwh/m^2)	Waste (kg/m^2)	Cost (ecu/m^2)	Shading (%)
E_1	4.2	1.5	125	5	0.7	0.4	58	6	0.13	0.6	12	80
E_2	3.0	2.2	210	3	1.0	0.6	35	2	0.52	0.2	14	65
E_3	3.6	3.7	185	1	1.2	0.2	62	7	0.64	0.5	8	52
...	...	...	...	...	...	...	...	...	...	...	...	...
E_{13}	4.2	3.4	125	2	0.7	0.3	58	5	0.13	0.7	12	58
E_{14}	3.6	2.2	185	3	1.2	0.6	62	2	0.64	0.2	8	65
E_{15}	4.8	1.8	165	4	1.1	0.5	43	4	0.31	0.3	9	45

Table 3: Actual values of statistical indicators of performance for element alternatives at each phase
(Units are non-dimensional)

Element	Manufacture			Construction			Occupancy		
	Mean	Sta.Dev.	Var.Coe.	Mean	Sta.Dev.	Var.Coe.	Mean	Sta.Dev.	Var.Coe.
E_1	6.40	4.41	0.69	5.78	3.04	0.53	4.45	3.90	0.88
E_2	6.62	2.61	0.39	6.40	4.41	0.69	4.75	3.84	0.81
E_3	5.99	3.78	0.63	3.98	4.24	1.07	5.95	3.99	0.67
...	...	...	...	...	...	...	...	...	...
E_{13}	6.15	3.42	0.56	6.80	2.57	0.38	5.42	3.83	0.71
E_{14}	6.40	0.94	0.15	3.98	4.24	1.07	6.47	4.38	0.68
E_{15}	5.26	3.22	0.61	5.16	2.58	0.50	8.38	1.30	0.16

Table 4: Ranked alternatives and phases with above-average utility values

Rank	Manuf.		Constr.		Occup.		Life cycle		Phase	
1	E_{14}	9.64	E_{13}	9.48	E_{15}	9.84	E_{15}	7.42	Constr.	5.36
2	E_6	8.12	E_5	8.16	E_4	9.72	E_6	6.61	Manuf.	5.08
3	E_2	7.62	E_{11}	7.82	E_{12}	8.43	E_{13}	6.21	Occup.	4.83
4	E_7	7.56	E_{15}	7.15	E_6	5.90	E_5	5.84		
5	E_{13}	6.00	E_1	7.00			E_4	5.80		
6	E_3	5.34	E_8	6.59			E_7	5.78		
7	E_{15}	5.27	E_{10}	5.95			E_{11}	5.70		
8			E_7	5.56						
9			E_4	5.54						

6 References

Aygun, M. (1998) Analytical comparison of buildings in terms of environmental impact criteria, *CIB World Building Congress*, Gaevle, Sweden, pp.897-904.

Beccali, G., Cellura, M. (1996) Life cycle assessment of building materials: A comparison by Electre methodology, *Durability of Building Materials and Components 7 (ed. Sjoestroem)*, E.& F. N. Spon, London, pp. 813-823.

Haas, M. (1998) the TWIN-model, an environmental calculation method as performance concept, *CIB World Building Congress*, Gaevle, Sweden, pp.1831-1838.

Kohler, N., Klingele, M. (1996) Simulation von Energie und Stoffflüssen von Gebaeuden waerend ihrer Lebensdauer, *International Symposium of CIB W67: Energy and Mass Flow in the Lifecycle of Buildings*, Vienna, Austria, pp.213-218.

Le Teno, J.F., Chevalier, J.L. and Rubaud, M. (1996) INIES - A framework to compile information on building products' environmental quality, *CIB World Building Congress*, Gaevle, Sweden, pp.965-972.

Lounis, Z., Vanier, D.J. and Lacasse, M.A. (1998) A discrete stochastic model for performance prediction of roofing systems, *CIB World Building Congress*, Gaevle, Sweden, pp.305-314

Maggi, P.N., Rejna, M. and Ravetta, F. (1998) Functional analysis as a method to design new building components, *CIB World Building Congress*, Gaevle, Sweden, pp.333-340.

Vanier, D.J., Lacasse, M.A. and Parson, A. (1996) Modeling of user requirements using product modeling, *CIB-ASTM-ISO-RILEM 3rd International Symposium: Application of the Performance Concept in Building*, Vol.2, Tel Aviv, pp. 6-73-6-82.

Weibel, T. (1996) Oekoinvantare und Wirkungsbilanzen von Baumaterialien, *International Symposium of CIB W67: Energy and Mass Flow in the Lifecycle of Buildings*, Vienna, Austria, pp.207-212.

175 ENSURING BUILDING SERVICEABILITY AT THE DESIGN STAGE

R. Becker

Israel Institute of technology, Haifa, Israel

Abstract

With the increase in standards of living most new building are expected not only meet safety requirements, but also to provide adequate serviceability. The paper presents the basic set of universal serviceability requirements. However, despite the explicit expectations many new buildings still do not meet them. The paper identifies two main causes to this situation: the lack of a systematic approach to the subject during the design stage, and the absence of a defined party that should be responsible for its implementation. It suggests how to bridge these gaps, discusses the difficulties of implementing the new process and defines procedures for making it feasible.

Keywords: Serviceability, design stage, safety, engineering, dimensions

1 Introduction

The definition of building serviceability is not unique and in various articles one may thus find different topics addressed under this same title. In the present paper serviceability is regarded in its broader, maybe even its broadest, context within the framework of the performance concept in buildings.

The analysis in this paper deals with the question: which aspects of serviceability can be properly addressed during the design stage, and to what extent can they be solved satisfactorily? It is based on the statement that a well-performing building is one that fulfills a multitude of performance requirements, which are comprised of three main groups: cultural, safety and serviceability requirements.

Durability of Building Materials and Components 8 (Volume Three). *Edited by M.A. Lacasse and D.J. Vanier*. Published in 1999 by NRC Research Press, Ottawa ON K1A 0R6, Canada. ISBN 0-660-17742-0

Cultural requirements (aesthetics, spiritual value, symbolism, status, philosophical or social statement, urban ecology, etc.) cannot, and probably should not, be quantified. Their fulfillment is the ma or aim during the conceptual architectural design stage, and in many projects is carried through the entire design process. The quality of their fulfillment depends mainly on the architect's creative abilities, and may strongly affect the mind and spirit of the building's regular occupants and other people who use or come near the building. However, it has little or no effect on the ability of users to perform their activities within the building. Moreover, there are many examples of buildings with a high level of cultural value and a very poor quality of serviceability conditions, leading to a low level of user satisfaction.

On the other hand, the level of fulfillment of safety and serviceability requirements affects the level of users' ability to perform their every day activities within the building, and as a consequence may also affect the state of mind and spirit of building occupants. However, when they are fulfilled without fulfillment of the cultural requirements a building will be dull and intellectually insignificant, but the specific occupants and users may still be satisfied and feel comfortable with the building.

The social aspects of this contradiction are of major significance to mankind and to urban development. Some may even claim that buildings of the first type are still an asset to society and their construction is highly justified, while buildings of the latter type are a menace to cultural evolution and should be prevented. As it is not the target of this symposium to deal with this question, the present paper will also avoid it and limit itself to the other aspects of a well-performing building.

2 What is a serviceable building

A building provides a satisfactory level of service to its occupants if at all times it satisfies the safety and serviceability requirements, that are outlined below.

The following list essentially summarizes the safety requirements:

- Structural safety - the building's structure should be absolutely stable, and have a sufficient level of safety against reaching an ultimate limit state under regular and extreme loads, that may occur during its life expectancy.
- Fire safety - the building should not compose a fire hazard to its surroundings; its internal traffic should be sufficiently clear and enable safe evacuation of the occupants upon fire; spread of fire should be limited; and there should be a margin of safety against an ultimate limit state of the structure as long as fire fighters may be in the building.

- User safety and health - dimensions of building parts should prevent falling to a lower level by bending/climbing or by bumping/penetrating; friction coefficients of flooring should prevent slippage on floors; surface materials' texture should be safe against tactile injury; and materials should not emit excessive amounts of hazardous chemicals into the habitable spaces.

It is usually the primary task of the engineers ("structural engineer", "safety engineer", "consultant engineer", etc.) to address these requirements during their design and detailing. As most codes and compulsory standards guide the designer in producing adequate solutions, it is seldom that buildings do not provide the expected level of safety.

However, a safe building may still be inconvenient during every day activity. Building serviceability requirements are composed of a larger and more varied set of topics. Some of them are related to furniture, appliances and other pieces of equipment. This paper addresses only the serviceability requirements related to the built parts of the building, i.e. the parts designed by the main architect and engineers, and usually constructed by the main contractor. The following list summarizes the most universal requirements of this kind. There may of-course be additional local requirements that stem from ways of living and local culture:

- Functionality - the building's spaces and their proximities should be so designed and dimensioned to suitably accommodate the functions and activities of the occupants and the relevant equipment (including furnish-ability/storage/service systems etc.). When subdivision is done after final sales or rent, this requirement can be applied in its entirety only after the final users are known. The spatial requirement in this case is that the free space on each floor would be as large as possible and not obstructed by too restrictive walls and columns.
- Physical Comfort - adequate dimensions should be provided to stairs, stairwells, passages and corridors, heights of window and balcony balustrades, and any other parts that may restrict movement or any other activity; thermally, acoustically and visually suitable internal conditions should prevail within the building spaces while conserving energy and the environment; and surfaces normally reached by occupants should have a pleasant texture.
- User well being - levels of moisture, aerosols, volatile compounds, gases, odours, bacteria, fungi, chemicals, fibers and particles within building spaces should be below threshold values that may contribute to the sick building syndrome.
- Psychological comfort - deflections, movements, vibrations and differential slip of building elements (not only of structural components) under regular service conditions should not be noticeable, should not cause noises or squeaks, and even under extreme temporary loads should not grow beyond a level that may cause panic; the building layout should be clear and provide a sense of orientation; and space dimensions and their proportions should be pleasant.

- Preservation of property - water should not leak through the building fabric, and building parts should not be inflicted by moisture, condensation or mold; building elements and surface materials should be free of cracks/peeling/tearing/breakage and sorts of other visible damage.
- Durability - building elements should maintain a minimal expected level of performance despite the deteriorating effects of weather (solar and ultra-violet radiation, moisture, drying, cyclic heating and cooling, etc.) of mechanical forces (friction, abrasion, differential expansion and contraction, erosion, etc.) of electrochemical corrosion and of biological degeneration.
- Maintenance - building parts (including service systems) that need maintenance should be easily and safely accessible for inspection, cleaning, painting, oiling, sealing, fastening, etc.
- Accommodation of change - the internal layout of spaces and their dimensions should not be too restrictive, and it should be possible to modify them to some extent (without endangering the building's safety) in order to cater for new demands/life styles/technologies/etc.

Most of these requirements are still not listed explicitly in codes and standards, and their fulfillment is not considered a primary task of either the architect or the engineer. In most cases they are addressed sporadically and inconsistently, depending on the level of awareness of the client and his advisors or of any party within the design team. In addition the knowledge, and in some cases expertise, needed to supply proper solutions to many of these requirements is not part of the designers' basic education.

3 Ensuring building serviceability

With the increase in standards of living most new buildings are expected not only to meet safety requirements, but also to provide adequate serviceability. In the developed countries this situation prevails nowadays even for low-cost housing, public buildings, army buildings and even prisons. Despite these expectations many new buildings are still very poor from the serviceability point of view.

The main causes to this situation are:

1. Lack of a systematic approach to the subject during the design stage, and
2. Absence of a defined party that should be responsible for its implementation.

A significant change can be achieved by bridging these two gaps. The following presents a possible bridge, the difficulties that rise in establishing it and means for overcoming them.

A systematic approach to serviceability can be derived by strictly clinging to the main ideas of the performance concept, and then by adoption of means and tools from the well-established procedures of structural engineering design, and process engineering.

To complete this task the following steps have to be accomplished:

- If the building is design for a defined purpose and known use: prepare a detailed list of the user groups, taking into account the maximum size of planned and future groups. List their activities throughout the building and over time, and prepare a list of their spatial proximity needs. Plan the building spaces according to proximities and approximate required sizes of spaces.
- If the building is designed for unknown users (to be sub-divided only upon rent or sale): prepare a list of potential user groups and their general gross space demands.
- For each user/activity prototype establish the relevant (usually quantitative) criteria that correspond to every serviceability requirement in the list above.
- For every building space and element combine all the criteria of the same sort and define the most demanding criterion.
- Design the specific space, element, component, detail, material, etc. to meet the specified criterion (including final spaces' dimensions when final sub-division is relevant).
- Evaluate the design (if required by quantitative analysis) in order to verify compliance with the specified criterion.
- Do so for all criteria, modifying the already determined (space, element, component, detail, material, etc.) decisions if necessary, but without violating previously met criteria.
- When all criteria are supposedly met, re-evaluate the entire set of decisions to ensure completeness.

This comprises a structured engineering-type design process, including the rigor and discipline (notwithstanding some quite tedious work and numerical analysis) that such a process is based upon. These features are not common during architectural design stages and processes, as they are not intrinsically required for obtaining creative and ingenious architectural solutions. It is also obvious that any design activity that requires a quantitative approach and calculations, or higher level numerical analysis, is not performed nowadays by the architect, and probably would not be performed by him/her in the near future.

On the other hand, when one looks at the design process and its internal dynamics the architect is clearly the leader, and the one who cares about many aspects that are not safety related, whereas the engineers are in most cases safety-oriented. For this reason it might probably be natural to expect that the architect would be the responsible party for serviceability.

There is no simple immediate resolution to this conflict, but it is clear that adding the knowledge contents of serviceability aspects to professional education has a meaningful potential for improving the current situation.

Re-modeling of architectural education would solve it only partially. This is an essential step in raising consciousness, so that serviceability in general is not ignored during building-program generation, and during conceptual, preliminary and other stages of the architectural design process. It will not change the working procedures, and thus, will not create the new setup that is essential for the rigor required in order to ensure that serviceability is evaluated in detail.

Broadening the scope of Civil Engineering education, and particularly that of Building Engineering, is another venue. This has a strong potential for generating a new type of engineering designer, and of re-engineering the design process for serviceability. However, at these engineering schools serviceability aspects were for many years regarded as inferior from the point of view of their scientific content, and assumed to require a lower level of intellectual capacity. For this reason it is not obvious that this venue is an immediate one. In order to make it feasible, internationally accepted detailed model curricula have to be established. They should include basic scientific subjects, such as "human ergonomics", "heat and mass transfer in buildings", "durability of building materials", etc., as well as design oriented subjects such as "the building envelope", "internal circulation and traffic", "dimensions and space allocation", and design projects. When the entire set of relevant serviceability subjects is combined with the regular subjects of building and/or structural engineering a new course of studies would emerge, that may lead to the required curriculum for educating the relevant designer.

Education of new professionals has its effect in the long run only. For more immediate results the almost only means is incorporation of serviceability requirements into official performance specification documents and building codes. As in most countries codes cannot enforce requirements that are not health or safety oriented, the serviceability acceptance criteria should be placed as recommendations. These documents should include at least recommendations for "minimum levels".

However, where possible or relevant, "preferred levels" or "recommended levels", as well as "top levels" (i.e. levels beyond which no additional benefit to building serviceability is gained) can be added. In addition to the requirements and criteria it is necessary to include the assessment or evaluation methods for every criterion. Builders and entrepreneurs are usually opposed to the preparation of these sort of documents, as they tend to be regarded as text books by the non-expert engineer or local jurisdiction, and to some extent may be applied too strictly without sufficient judgement. Moreover, dissatisfied customers may use (abuse) them to sue the builder or designer although no real harm has been caused by incomplete compliance.

4 Conclusions

Large parts of the knowledge base for incorporating all serviceability aspects during the design stages do exist, but the professionals involved in the design process do not apply them properly and consistently. A combination of advanced professional education programs with incorporation of serviceability recommendations in building codes may lead to a change in attitude. Despite some interim misuse, that this move may cause, the benefit to the quality of most buildings and to enhancing the satisfaction of users seems to be a valid cause for considering its implementation.

176 COMMUNICATING PERFORMANCE REQUIREMENTS — TOOLS FOR TRANSFERRING CLIENT-ORIENTED MAINTENANCE INFORMATION

A.A.J. Damen and M.H. Hermans

Damen Consultants, Rotterdam, The Netherlands

Abstract

The building industry is changing from a supply-oriented towards a demand-oriented market. Quality and value for money are becoming key-issues. The communication on buildings has to change accordingly: from technical information on the composition of the building and building costs towards functional information on the performance of the building and costs-in-use. The maintenance sector is influenced by these changes. Maintenance should be adapted to the requirements of building owners and users. There is a need for tools to "translate" the technical maintenance information into information relating to the performance of the building maintained and vice versa. The building manager is in the centre of the information flow between client and maintenance staff.

This paper describes tools, which can be used as communication means between building manager and tenant, between the maintenance department and the management department within an organisation, and between the inspectors and the maintenance manager.

Keywords: Maintenance information, performance requirements, prioritisation, client-oriented information

1 Introduction

Each building owner and user will have his own specific requirements regarding the building stock they own or occupy. For some, the return on investment will be the main issue (for instance in the office market), for others specific functional features may be essential (for instance for a laboratory building). Building maintenance will have to be attuned to these diverse requirements. This paper describes a tool, which can be used to prioritise maintenance activities.

Durability of Building Materials and Components 8 (Volume Three). *Edited by M.A. Lacasse and D.J. Vanier*. Published in 1999 by NRC Research Press, Ottawa ON K1A 0R6, Canada. ISBN 0-660-17742-0

Communication on maintenance has concentrated for a long time on detailed, specific technical information ("screws and bolts"). The increasing need to explain to the client what quality he gets for his money supports the development of tools facilitating communication between technical and non-technical parties. The tool visualises the effects of a specified maintenance policy on the performance level and maintenance costs of a building. The tool can facilitate information exchange between tenant and building manager or between technical staff and management within one organisation.

Visual aids are not only beneficial when explaining technical issues to a non-technical audience. They have also proven to be very useful in training building inspectors. Client-oriented maintenance planning strongly depends on an objective and accurate report of the actual condition of a building. Although inspectors can be carefully trained in the way they should describe a building and its defects, experience is still an important factor in the reliability of inspection results. Pictures can help to build up a frame of reference for building inspectors is demonstrated.

2 Performance-based prioritisation of building maintenance

The new generation of client-oriented maintenance planning systems takes the requirements of the building owner and user as a starting point. Maintenance is understood to be a means to optimise investments, rather than being an aim in itself. The client requires information on the maintenance costs and performance of his building in relationship to other, competitive, buildings. The focal point is the required performance compared to the budget available. Budgets will be limited and requirements can easily exceed the amount of money at hand. It is therefore important to set priorities and to list the requirements in order of merit. Maintenance activities are based on these priorities.

For different buildings the set of requirements and priorities will differ. The function of the building, its age, cultural value, location and currency in combination with the market situation determine the required performance level. Even for parts of the building the priorities can be dissimilar: public spaces may be kept at a higher maintenance level than private space and the main entrance will probably have a higher aesthetic aims than the back street entrance.

Rather than setting one maintenance level for the whole building stock, which is still common, professional real estate owners and managers are now looking for ways to differentiate the maintenance efforts between buildings according to priorities.

First, for each building (or set of buildings) an overview is made of the performance aspects an organisation wants to take into account when deciding on maintenance activities. Issues can be the financial consequences or the effects to the use of the building in relation to maintenance activities (table 1).

Table 1: Aspects for prioritising maintenance activities

Financial consequences of delay of maintenance activities
• Sequential damage to other components; • Increase of user complaints and increased costs of day-to-day maintenance to repair defects; • Increased migration rate due to dissatisfied users; • Decreased energy performance of the building.
Consequences for building use
• Health and safety of occupants is being endangered; • The primary production process of the user organisation is at stake; • The comfort of occupants is threatened; • The aesthetic value of the building may be lost.

The Dutch Government Building Agency, for instance uses the below "aspect / priority matrix" to define the urgency of maintenance activities (table 2).

Table 2: Aspect / priority matrix of the Dutch Government Building Agency

	Priority								
	low								**high**
Performance Aspect	**9**	**8**	**7**	**6**	**5**	**4**	**3**	**2**	**1**
1. Safety and health							■	■	■
2. Cultural and historic value						■	■	■	
3. Production process of client					■	■	■		
4. (Not defined)									
5. Aesthetics / image / annoyance			■	■	■				
6. Financial consequences or sequential damage		small	<10	■	50	■	>100	■	
7. Functioning of building component	■	■	■						

The next step is to relate the performance aspects to defects found in a condition-based inspection of the building: For each defect the impact of the defect on the defined performance aspects is indicated, for instance by means of a three point scale: low impact, normal impact, high impact. An example is given in table 3.

Table 3: Relating performance aspects to defects

Component: **Defect:**	**Bituminous roof cover** **Obvious, widespread erosion of or submerged gravel layer**
Performance aspects	**Impact (1=low, 3=high)**
Aesthetic aspects	1
Use	1
Indoor environment	2
Safety	1
Complaints	1
Sequential damage	3

If a defect has a high impact on a performance aspect with a high priority, it is obvious that maintenance should be applied to cure the defect. Therefore, the next step is to relate impact rate to priority and define the urgency of maintenance. For instance:

If aesthetic aspects are considered to be important, and have a high priority, defects having any impact on aesthetics should be prevented and urgently repaired, when occurring (impact rate 2 and 3). If aesthetic aspects are not important, though, an impact rate of 3 may be well allowable.

In this way, building maintenance can be geared to fit specific organisational requirements. Maintenance planning software can support an automated selection process of urgent activities. The inspection data will then contain information on the impact of defects on performance aspects. Previously, the organisation has filled-out a table with priorities and allowable impact scores per building or object. The planning system contains a filtering procedure, filtering only those activities from the inspection data, which are urgent. The inspector is trained to estimate the impact of defects, the organisation sets the maintenance policy in terms of priorities.

If the maintenance policy is changed, the filter is adapted and a new planning is made based on the altered maintenance urgencies. This allows an organisation to "play" with maintenance expenditures and see the effects of different choices to the performance level of the building. This provides more insight to the relationship between maintenance costs and supplied performance. Effects of budget cuts are made visible in terms of impact on performance provided and, vice versa, a set required performance level results in a required maintenance budget given the actual condition of the building. This way of working can therefore support communication between the technical staff, responsible for maintenance planning, and the financial staff, responsible for maintenance budgets, or between management, responsible for defining the maintenance policy, and technical department responsible for the execution of maintenance activities.

3 Communication between maintenance managers, tenants and management

To support communication processes between policy makers and technical staff, the use of visual aids can be considered. One of the problems encountered in the transfer of information on building maintenance, is the difference in backgrounds of the parties involved: A technical background for those responsible for planning maintenance activities and a financial or managerial background for those responsible for policy making. A similar problem exists in the communication between tenants and building managers. Tenants will be interested in which building quality they may expect for their rent, while at the same time the building manager may want to agree upon both the quality of owner-paid maintenance as well as the quality of tenant-paid maintenance.

To make the required maintenance level literally visible, photographs of buildings in different conditions may be helpful. In the Netherlands, KPN Real Estate & Facilities uses this means to enhance communication between client and real estate facilitator (KPN).

KPN uses two performance aspects to differentiate between maintenance levels:

- The Aesthetic performance;
- The Functional performance.

For each, five performance levels are defined. The required maintenance level is defined as a two number digit, with the first number indicating the required functional performance level and the second representing the required aesthetic performance level (table 4).

Table 4: Maintenance levels determined by functional and aesthetic requirements

		Functionality				
		Very high (1)	High (2)	Average (3)	Low (4)	Very low (5)
Aesthetics	Very high (1)	1.1	2.1	3.1	4.1	5.1
	High (2)	1.2	2.2	3.2	4.2	5.2
	Average (3)	1.3	2.3	3.3	4.3	5.3
	Low (4)	1.4	2.4	3.4	4.4	5.4
	Very low (5)	1.5	2.5	3.5	4.5	5.5

A required maintenance level 3.4, therefore stands for an average functional performance and a low aesthetic performance.

To visualise each specified maintenance level, a picture book has been made. The book presents each possible combination of performance level (1.1 up to 5.5). It explains what the required performance level in each case actually means and shows a photograph with a building component with the maintenance level indicated (table 5).

The normal maintenance level depends on the function of the building. If a building should be representative, for instance bank buildings, the normal maintenance level can be based on a high functional and aesthetic performance. If a building is used as a warehouse, maybe a low aesthetic and functional performance is acceptable.

The maintenance costs will depend on the maintenance level chosen. If the maintenance costs of a maintenance level assuring an average functional and an average aesthetic performance (level 3.3) are said to be 100%, the costs of lower and higher maintenance levels can be defined by an adapted percentage. For instance, level 2.2 means 150% of the average maintenance costs, level 4.5 represents 40% of the average maintenance costs.

The average maintenance costs will depend on the type of building: its function, its age, its size, its composition. If for each building type, the "average maintenance costs" are determined, the costs of other maintenance levels can be deduced.

Table 5: Visual aid to support communication on maintenance levels; Source: KPN Real estate & Facilities

Maintenance level 2.3

	Functionality				
Aesthetics	Very high	High	Average	Low	Very Low
Very high					
High					
Average		2.3			
Low					
Very low					

Functional requirements class 2 **high functional requirements**

Functional defects may occur incidentally under unfavourable (weather) conditions. Examples are draught and limited water leakage during extreme wind or rain. The use of the building and the primary production process should not disturbed.

Aesthetic requirements class 3 **average aesthetic requirements**

Aesthetic defects such as discoloration and pollution may occur in a small extent. Graffiti will be removed. Loss of gloss and other signs of ageing of paint layers are acceptable. Erosion and technical shortcomings of the building are acceptable, unless there is a strong negative impact on the appearance.

KPN Real Estate & Facilities, for instance, has defined the maintenance levels for the different types of buildings of their post group. The average maintenance costs for this specific type of buildings are connected to the levels 2.4 and 3.3. Depending on the exact function and objectives of a building, the actual required maintenance level is identified, by means of an intended maintenance level, and a range of acceptable levels around this level. The costs connected to this maintenance level are a derivative of the costs connected to levels 2.4 and 3.3 (table 6).

Table 6: Relationship between maintenance levels and maintenance costs

	Maintenance level															
	1.1	1.2	1.3	2.1	2.2	2.3	2.4	3.2	3.3	3.4	3.5	4.3	4.4	4.5	5.4	5.5
Buildings with public function					X											
Buildings without public function									X							
Temporary post buildings (for sale within < 2 years)									X							
Temporary post buildings (for sale in 2 – 5 years)									X							
Partly empty buildings (for sale within < 2 years)													X			
Partly empty buildings (for sale in 2 – 5 years)													X			
Dwellings									X							
Empty buildings														X		
Cost index	225	200	150	200	150	125	100	125	100	75	50	75	50	40	40	25

The information provided serves communication between tenant and building manager: The tenant indicates which performance level he would require. The building manager presents the required maintenance budget to achieve this performance level. The tenant then can adjust his requirements, if the required costs are too high, or set aside the required budget.

Although KPN uses the tool for external purposes, similar tools are very useful in the communication between managerial and operational departments. Management sets the maintenance policy, by means of the photographs and performance levels provided. The executive department indicates which costs are connected to the requirements. The budget provided by the management should either fit the costs involved with the requirements or the requirements should be decreased.

4 Pictures and training of inspectors

Photographs also prove to be extremely useful in training building inspectors. Experience has shown to be an important characteristic of a good inspector. A frame of reference is essential to accurately indicate the actual condition of a building component. Experience does not only help to recognise the materials encountered, it also helps to assess the stage of deterioration of a component and its impact on the performance of the component. Pictures can help to build up a frame of reference for inexperienced inspectors.

In a European research project, of which Damen Consultants was the project co-ordinator, pictorial information was gathered for over a hundred building components. For each component, a description was made of the composition and functioning of the component. Also the defects, which could be encountered and how those defects should be measured and assessed is presented. For the different stages of deterioration photographs were provided (Figure 1). The defect sheets are now being used for training purposes.

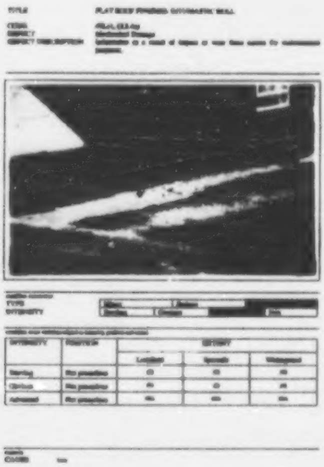


Fig. 1: Example of defect sheet

5 Conclusions

This paper presented three tools, which can be used to enhance communication about maintenance in a changing market. The market requires client-oriented information, rather than technical information. The tools presented in this paper connect maintenance to user and owner requirements. Decisions on property should be based on the objectives of the client organisation. Pictures can be an important support for information transfer between parties with different backgrounds. They can also be used in training operational staff. Each tool described is currently being applied in day-to-day building maintenance practice in various organisations. The results are promising.

6 References

Damen Consultants (co-ordinator), *Condition Assessment and Maintenance Strategies for Buildings and Building Components. Final Documentation*, Brite Euram Project BE 4213, Rotterdam, June 1996

Damen Consultants, *Condition Assessment of Buildings and Standardisation of Maintnance* (in Dutch), Stichting Bouwresearch, Rotterdam, 1998, ISBN 90-5367-251-6

KPN Vastgoed, *Standardisation of the Maintenance Level of Buildings* (in Dutch), 1997

177 ARE FACILITIES MEASURING UP? MATCHING BUILDING CAPABILITIES TO FUNCTIONAL NEEDS?

G. Davis and F. Szigeti

International Centre for Facilities, Ottawa, Ontario, Canada

Abstract

Building occupiers increasingly expect workplace facilities and service providers to meet rigorous, consistent and measurable demands for quality, which we define as functionality and serviceability (capability to perform as and when required). A new set of standard processes and tools, recently approved by ASTM and registered as American National Standards (ANSI), responds to this need. They give both users and managers of facilities the means to determine functional requirements, measure the quality of facilities provided, and verify that those facilities match the stated requirements, in sum, to ascertain fitness for purpose. They are well suited for use with Total Quality Management (TQM), ISO 9000, and other Quality Management Systems. They can be used for benchmarking world-wide.

Keywords: indicators of capability, facility management, functional requirements, performance, portfolio assessment, service life, serviceability, total quality management, user needs.

1 Fitness for purpose, and business value

1.1 Link business value to corporate strategy

The Serviceability Tools and Methods (ST&M) enable a company to put numbers to the relative *business value* of an individual facility, or of a portfolio of real property, that is, how well it supports, or enhances, or impedes, the strategy of the business, and the functioning of the occupants.

Durability of Building Materials and Components 8 (Volume Three). *Edited by M.A. Lacasse and D.J. Vanier*. Published in 1999 by NRC Research Press, Ottawa ON K1A 0R6, Canada. ISBN 0-660-17742-0

1.2 Business value is *not* real estate market value

This is quite separate from how the real estate market prices a particular piece of land and the buildings on it. Standard procedures for appraising the real estate market value of a building are accepted in the real property industry. Until recently, there was no standard way for putting numbers to the relative business value of a property.

Instead, managers used their best judgement when comparing buildings as a special type of "tools of production". These informal estimates were not adequate for benchmarking the business value of a portfolio, nor for comparing portfolio strategies based on business value.

At the same time, building occupiers increasingly expect workplace facilities and service providers to meet rigorous, consistent and measurable demands for quality or functionality.

1.3 Measure fitness for purpose

ST&M responds to these needs. It enables both users and managers of facilities to measure fitness for purpose. It enables them to numerically link functional requirements to business strategy, to measure the functional capability of facilities provided, and to verify that those facilities match the stated requirements. ST&M, recently approved by ASTM and registered as American National Standards, is also well suited for use with Total Quality Management (TQM), ISO 9000, and other Quality Management Systems. ST&M can be used for benchmarking worldwide. ST&M is a macro, broad-brush methodology, appropriate for strategic decision-making.

1.4 Serviceability = *capability* to perform

The *serviceability* of a facility, such as a workplace, or a home, is its capability to support the activities or functions of users and owners, as and when required. Most organisations and work groups have only a few generic types of functions, such as general purpose office functions, or office functions requiring special security provisions, or receiving many visitors, or office functions requiring special high-technology, or a mix of office and "dry" laboratory functions. For each type of function, the facilities are required to have a different mix of functional capabilities, that is, a different profile of serviceability.

The Serviceability Tools and Methods (ST&M) provide for setting the required capability to meet a range of functional performance requirements, each requirement to a specified level of performance. ST&M also includes tools and processes to assess the serviceability of buildings, and of designed facilities that have not yet been built or remodelled. A roll-up of serviceability ratings gives an overall view of the business value of a portfolio of facilities.

1.5 Easy and safe to use

ST&M can be easily and safely adapted to reflect the particular needs of a specific organisation. For organisations with many facilities that house similar types of functions, these tools and methods also capture a systematic and consistent record of the institutional memory. For smaller organisations, ST&M can cut costs and reduce risks for facility planning. For any organisation, ST&M speeds up the functional programming process and provides comprehensive ratings quickly, yet without being simplistic.

Using ST&M is simplified and speeded with new software, which also produces quick graphic reports for management decision, and can feed data to enterprise data systems.

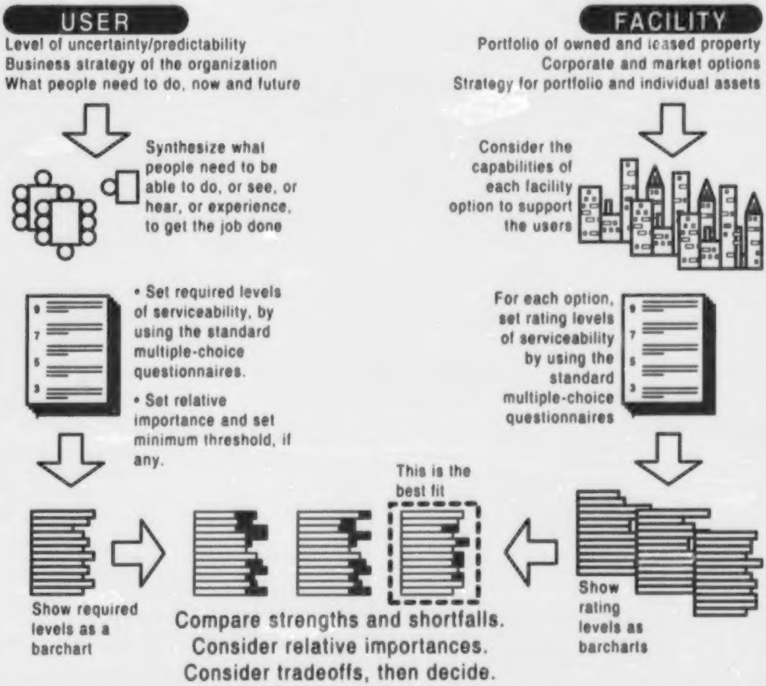

USER
Level of uncertainty/predictability
Business strategy of the organization
What people need to do, now and future
FACILITY
Portfolio of owned and leased property
Corporate and market options
Strategy for portfolio and individual assets
Synthesize what people need to be able to do, or see, or hear, or experience, to get the job done
Consider the capabilities of each facility option to support the users
9
7
5
3
• Set required levels of serviceability, by using the standard multiple-choice questionnaires.
• Set relative importance and set minimum threshold, if any.
For each option, set rating levels of serviceability by using the standard multiple-choice questionnaires
9
7
5
3
This is the best fit
Show required levels as a barchart
Compare strengths and shortfalls.
Consider relative importances.
Consider tradeoffs, then decide.
Show rating levels as barcharts

Fig. 1: Finding the best fit based on "business value"

2 Serviceability Tools and Methods (ST&M) in practice

2.1 Framework for choice and comparison

ST&M is a framework, process and tools by which the "user requirement profile" for a facility can be tailored to a given situation, and compared to other profiles using a standard classification system. These tools and methods do *not* specify in advance what level is "correct". That is up to the stakeholders for each organisation or facility. They use ST&M to choose among options.

ST&M includes two matched, multiple-choice questionnaires and scales, formats for describing the organization, and function-based tools for estimating how much floor area an organization needs. Calibrated multiple-choice questionnaires and bar-chart profiles are used to:

(a) Determine the functional needs of users of facilities, such as occupants, facility managers and investors, vis-à-vis corporate business strategy and other objectives.

(b) Rate the capabilities of facilities to meet those needs.

(c) Compare the two.

(d) Compare the capabilities of a facility to that of other facilities, e.g. for benchmarking.

(e) Assess the serviceability levels of the design for a future facility, i.e. not yet built or remodelled.

The matched, multiple-choice questionnaires at present cover over 100 serviceability topics, including over 340 building features. Each questionnaire offers choices on a scale from 1 (least) to 9 (most) capability. One questionnaire describes customer needs (demand), and for each topic specifies relative importance and, when applicable, minimum threshold levels. The other questionnaire rates facilities (supply). The focus is on the customer.

The scales are calibrated to the building inventory in a country or group of countries, so that a level 5 reflects what is typically present in a mid-class facility, *not* what is a typical mid-level requirement. No occupant group is likely to specify a requirement profile of level 5 on every topic. Instead, typical requirement profiles for each generic category of users tend to evolve over time. For instance, requirements to accommodate information technology have risen faster than the general building stock has responded, and requirements for indoor air quality are rarely at a level 5.

2.2 Measurably link facilities to end-user needs

One of the unique characteristics of ST&M is the importance of end-user language on the demand side, so that the process can be transparent to all stakeholders. Everyone who uses ST&M can fully understand what each requirement statement means. To set the level of requirement for each topic of serviceability, a choice is made as to which of five statements best describes the level or amount of capability required, from level 1 (least) to level 9 (most). ST&M provides for setting, when necessary, a minimum threshold level of serviceability, below which the facility would be seriously dysfunctional. The relative importance of each requirement is also specified, ranging from exceptionally important to minor importance. The recommended processes are participatory, consensus-building, and include all stakeholders.

Because multiple choice questions are used, rather than open-ended questions or checklists, requirement levels specified by one group can be compared to levels of another group. For instance, requirements in one region can be compared to requirements in another; requirements of one department can be compared to others in that organization, or to comparable departments in other organizations. For the first time, benchmarking of requirement profiles is practicable, between companies, or from one country to another, or even between governments.

Figure 2, below, contains an excerpt from one of the standard serviceability scales. It shows both the requirement scale, in the left-hand column, and the scale for rating (see section 2.3, below) in the right-hand scale. When actually gathering information for the requirement profiles, e.g. by interviewing or conducting a focus group, respondents are given a questionnaire work-book that only contains the requirement scales. Similarly, when rating the serviceability of a facility, the rater uses a work-book that contains only the rating scales, e.g. from the right of this example.

2.3 Consistently rate functional capability

The rating scales provide *indicators* of serviceability. Each rating scale presents several descriptions of features ranging from level 1 (least) to level 9 (most). The features are chosen and described as indicators of the level of capability of the facility vis-à-vis that topic. For each topic, the person doing the rating is asked, "Which of these statements best describes what is physically present in the facility, or shown in the design?" The questions contain descriptions of physical features that typically indicate quality and functionality of a facility.

This produces much more consistent, systematic and comprehensive ratings than would be obtained in each instance by asking an experienced professional for a judgement on the "goodness" of facility design or condition. ST&M avoids the inescapable differences in experience, qualification and judgement from one professional to another. It also avoids the variations in "goodness" that professionals would impute to a facility, depending on each person's understanding of what it is to be good for, that is, it separates the judgement of capability from the level of requirement. The serviceability of a facility is independent of what entity now occupies it, or might occupy it in the future.

Thus, the rating scales are *not* outline specifications. ST&M was designed to bridge between "functional programs" written in user language on the one side, and "outline specifications and evaluations" written in performance language on the other. Although the rating scales are written in technical language, they describe indicators, rather than specifying what must be present. If this set of indicators were applied as preliminary technical specifications, for instance in a design competition, they would unduly constrain design options unless other, ". . . or equivalent", options were also permitted.

2.4 Use to manage both a portfolio and individual assets

The Serviceability Tools and Methods have been used to answer questions such as: How well does our portfolio support our business strategy? Should we stay in this facility or dispose of it? Which properties in the portfolio have the worst problems of deferred maintenance? How should we change our offices so that they support, instead of impeding, the change in corporate culture we must make? How do our facility requirements compare with what is typical in the companies we benchmark against? Which properties on offer should we decide to negotiate about? Does the functional quality of designs proposed for new or remodeled facilities meet requirements, i.e. find out during design instead of after construction or move-in?

Each set of scales can be used separately and independently of the other. Each can be used to add understanding and information about the other. ST&M generic profiles can also be used in lieu of actual occupants, as a kind of surrogate, when occupants are not yet identified, for example to define what market niche to target.

A.11 Image to Public and Occupants --- Scale A.11.6. Identity outside building

	User Requirement Scale			Facility Rating Scale
9 ☐	Operations require maximum "exposure" to the public. The address, building and signage must be very easy for pedestrians or motorists to find and recognize, even for those unfamiliar with the locality.		9 ☐	○ **Identity of building:** The building is a well known landmark. The building and entrance are clearly visible and recognizable. ○ **Corporate identity and signage:** The organization's identity is clearly recognizable, and readily visible from all directions. Direction signs are placed at main nearby transit stops. ○ **Quality of external signs:** The building has special custom signage, e.g. stand-alone elements, special lighting, and full information. All signs are in as-new condition.
		8 ☐		
7 ☐	Operations require above average "exposure" to the public. The address, building and signage must be easy to find and recognize, even for those not very familiar with the locality.		7 ☐	○ **Identity of building:** The building and building entry are clearly visible to passing motorists and pedestrians, and recognizable. ○ **Corporate identity and signage:** The organization is well identified from all directions.; Signage is adequate, and clearly visible on every approach to passing motorists and pedestrians. ○ **Quality of external signs:** Building signage is appropriate and typical, e.g. street address, building name, principal occupant group(s). Signs have no visible deterioration.
		6 ☐		
5 ☐	Operations require average "exposure" to the public. The address, building and signage must be easy to find and recognize, for those familiar with the locality.		5 ☐	○ **Identity of building:** The building and building entry are visible to passing motorists. The building is identifiable, and not easily confused with its neighbors. ○ **Corporate identity and signage:** The organization is identified to a minimum level. Signage is generally visible to passing motorists and pedestrians. ○ **Quality of external signs** Building signage is appropriate and typical, e.g. street address, building name and, if appropriate, principal occupant group(s). Signs have no damage or major deterioration.
		4 ☐		
3 ☐	Operations do not require much "exposure to the public. Most visitors are "regulars". Corporate image is not a high priority.		3 ☐	○ **Identity of building:** The building is obscured by other buildings from some directions, and from people approaching along the street from one direction. The building is very similar and hardly distinguishable from adjacent buildings. ○ **Corporate identity and signage:** The organization is not clearly identified. Signs are obscured from some directions, or are in poor light. ○ **Quality of external signs:** Signage is minimal or impaired, e.g. minimal information, weathered surfaces, partly damaged.
		2 ☐		
1 ☐	Operations require that the office is obscure to the public, e.g. for security reasons		1 ☐	○ **Identity of building:** The building is obscured by other buildings until viewed from directly in front, or, the building is not distinguishable from adjacent buildings, e.g. facades are almost the same. ○ **Corporate identity and signage:** There is no evidence of the organization's identity on the exterior of the building. Signs are obscured, e.g. by vehicles or other buildings. Signs are very poorly located or hard to read, e.g. signs are too high on the building, too small, the lettering is too small or low in contrast, or signs are in shadow. ○ **Quality of external signs:** Signage is minimal or badly damaged, with incomplete information, e.g. no street number or building name.

☐ Exceptionally important. ☐ Important. ☐ Minor importance.

☐ Mandatory minimum level (threshold/criticality) = ☐ NA ☐ NR ☐ DP ☐ LI

Fig. 2: Example of a serviceability scale, showing both requirement and rating scales

2.5 ST&M bridges between users and providers

At the heart of STM is the process of "working with" the occupant groups and other stakeholders. This process of communication between the CRE and FM professionals and the other stakeholders, of valuing their input, of being seen to be responsive, is often as important as the outcome itself. It requires a change of attitude on the part of the CRE and FM groups about the way that they do business on a day-to-day basis. Using non-technical language is a key to communication with all stakeholders. They are not being asked to choose a particular building feature or technical solution. They are asked to describe what they do and how they work. What is important here is that, because there is a match between "what people need to do" and what the workplace can provide, the translation from non-technical to performance language is made explicit.

Although it is a standardized approach, it can be easily adapted to reflect the particular needs of a specific organization. For organizations with many facilities that house similar types of functions, STM captures a systematic and consistent record of the institutional memory. It speeds up the functional programming process and provides comprehensive, systematic, objective ratings in a very short time.

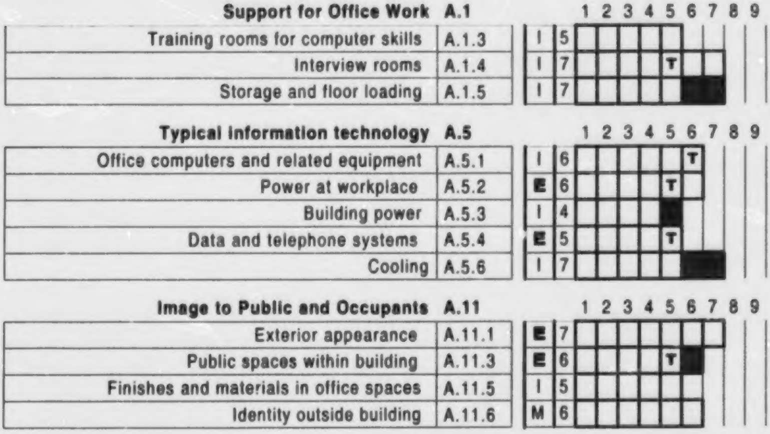


Fig. 3: Excerpt from a Barchart of Serviceability Levels compared to Requirement levels

Blank rectangles, e.g. for the top topic, A.1.3, indicate that there is a requirement for level 5 and the facility is rated at, i.e. capable of, level 5. For topic A.1.4, there is a requirement to level 7, which is met, and a minimum threshold requirement of level 5. For topic A.1.5, there is a requirement of 5, a capability of 7, so a surplus of two levels; there is a pattern in those rectangles.

2.6 Various categories of function

Several generic versions of the requirement profiles for offices have been developed up to now. These set out the levels of functionality and serviceability typically needed in North American office workplaces. They are for: general administrative office functions; administrative office functions with much public contact; administrative office functions with enhanced protection for sensitive information or for valuable papers, such as checks; and corporate headquarters.

ST&M has also been used for other functional categories such as software developers; maintenance shops; the main office building chancery of a country's embassy; quasi-judicial facilities similar to courts for non-criminal matters, laboratories, and so on. Work is under way to develop scales for a variety of other functional categories, such as health care, education, light manufacturing, and retail.

2.7 Several kinds of tools

ST&M includes several kinds of tools, along with procedures, documents and computer templates for using them. These are: (1a) functional requirement barchart profiles, (1b) building serviceability barchart profiles, and (1c) a match between these two profiles; (2) descriptive text about the organization, in a standard format; (3) quantity spreadsheet profiles; (4) building loss features (BLF) rating table; (5) footprint and layout guide for modular dimensions.

3 Case study examples

These tools and methods are now used in the private and public sectors in Canada and in the United States, and have been used in other countries, such as The Netherlands, New Zealand and Australia. Examples are summarized below.

3.1 Management of a large portfolio

In the late 1980's, the Department of Public Works of Canada needed tools and methods to provide user organisations (other government departments) with a more consistent response to requests for facilities, from region to region across the country. It also needed tools to provide consistent information about the condition and functionality of its portfolio of over 600,000 m2 in buildings, so it could become a more consistent quality provider of facilities, and so it could identify and estimate the cumulative capital requirements for replacement and renovation of its properties. It contracted with the International Centre for Facilities to develop what subsequently became known as ST&M.

3.2 Crash assessment program before major strategy review re invest, divest, renovate

A city needed to quickly decide which of its 40 major properties should be retained and upgraded, retained unchanged, or disposed of. This included both owned and leased property. City staff needed a review of about 40 properties within three months, so they could present a comprehensive portfolio management plan to the city council. Staff were trained in the use of ST&M, and a local architectural firm was trained at the same time. Serviceability rating profiles of all properties were completed on schedule. They became the basis for the city's portfolio management decisions. City council has since directed that the ST&M database be maintained, and updated with each significant change to a property.

3.3 Rusting out – make informed decisions about when to invest and when to divest

Several large organisations have recognised that because of past under-investment in capital maintenance projects, they now have no choice but to either divest of some properties, or to salvage them by immediate remediation. Each organisation has used ST&M to identify the relative seriousness of the remediation problems at each property, and to select functionally appropriate properties they expect to retain and remediate. ST&M also enabled them to immediately select and instruct engineers to do in-depth investigations at some sites, and to prepare cost estimates for remediation. To speed the initial scan, in some cases only that portion of the ST&M scales dealing with building condition, operation and maintenance were used for rating, while for other properties they also used the scales dealing with key aspects of functional support to occupants.

3.4 Portfolio management

A regulated public utility needed a strategy for managing its portfolio of 24 field maintenance stations. It needed to compare the general condition and functionality of each, so it could set priorities for disposition, rehabilitation, and upgrading. After using ST&M to rate the field stations and compare to requirements, it found that some facilities were in adequate condition, while others were impairing operational capability. The company decided that a few of the stations were so functionally inadequate that they should be disposed of, some were in need of major repairs, but could be salvaged, and a few were in good condition.

3.5 Capital budgeting for deferred maintenance

An insurance company had about 100 drive-in claim centres, most built at about the same time. It needed an assessment of the functionality and condition of each, so it could develop a portfolio management plan for the coming years. Using ST&M, functional strengths and concerns were reported, deferred maintenance and cost-to-cure were identified, capital budgets were adjusted, and staff were trained to continue use of ST&M, and keep the data current, after the initial one-year project. In a side benefit, the human resources group used the ST&M focus groups to start staff participation in defining new directions for the company.

3.6 Change in corporate culture

A public utility, with tens of thousands of employees and a very conservative, bureaucratic operating style, had been privatised, and its staff count had been halved. It is now changing its corporate culture towards a more entrepreneurial mode, with many "new-style" upper-level managers. Management recognised that its office facilities were hindering the culture change. For instance, although the work in some departments, and the new culture, required frequently changing project teams, the facilities could not accommodate them. Also, management had not recognised the seriousness of certain facility problems, such as with temperature control, indoor air quality, inadequate meeting facilities, and open office acoustics. The company used

ST&M to identify the problems, set priorities, and provide a knowledge base for planning the remediation. They developed new ST&M requirement profiles, and are using them in planning the rehab of their office facilities in several cities.

3.7 Project design-build

A multi-national company, planning a new corporate headquarters, used an ST&M requirement profile as the criteria for an invited design competition to select the architect. Then the company negotiated a design-build contract with an investor/-developer, using ST&M in setting performance criteria for the design-build contract. As the project proceeded, the company used ST&M to rate the detailed design for compliance the requirement profile.

3.8 Real estate brokerage

A national brokerage firm with a large commercial property business uses ST&M to gain competitive advantage (exclusive listings) vs. other brokers. It obtains some "listings" by providing its clients with ST&M ratings as a tenant service. The individual brokers pay the cost of ST&M reports out of their commissions, because ST&M is so attractive to their clients. The brokers need a fast ST&M response, typically five or six working days for a rating profile, or ten for a requirement profile.

3.9 Select property to rent

An office organisation needed space for a branch office, with about 5,000 m2 on one floor. They needed excellent access for their 1,000 to 1,500 visitors per day, most of whom come by auto. They already had a pre-approved ST&M requirement profile accepted by regional staff, so the urgent need was to rate candidate properties, and quickly start negotiating a lease. Using ST&M, six properties were reviewed in 2 days. One property met most but not all criteria, so two additional properties were proposed. Of the additional properties, one met all criteria, and was quickly leased.

3.10 Program a new office building.

A high-tech company, growing exponentially, urgently needed a first building on its new office campus. The preliminary requirement profile and the rating of their present facilities were accomplished in three working days. The requirement profile was completed and used as criteria for a build-to-suit project. Programming was simplified and speeded because ST&M gave the requirements for initial design

3.11 Building owner – Landlord

A huge multinational company moved its regional headquarters moved out of a prestige Class A building that it owned. In that city, the largest tenant wanted only low-rent offices for general administrative functions. The company obtained a "supply" profile from an ST&M rating of the vacant portion of the building. They found it matched the requirement profile for a niche market which was in short supply, and for which a potential tenant was known. The company successfully rented the vacant space within 3 months, at close to the highest rent levels in the city.

4 Conclusion

ST&M is useful for day-to-day use in real estate portfolio management, real estate and facility management operations, and property management, operation and use. As required by ISO 9000 processes, ST&M can be used to ascertain the explicit and implicit expectations and requirements of the user (customer), test how well the building (product) complies, demonstrate compliance, and document it. ST&M is valuable for research into building performance, because it provides a consistent, objective, numeric way of reporting that enables researchers at different times and places, and even different countries and cultures, to use and compare results by others. It is also a valuable communication tool between professionals and users.

5 References

Aronoff, S. and Kaplan, A. (1995) *Total Workplace Performance, Rethinking the Office Environment*, WDL Publications, Ottawa, Canada.

Baird, G., Gray, J., Isaacs, N., Kernohan, D., McIndoe and G. (1996) *Building Evaluation Techniques*, McGraw Hill, Wellington, New Zealand.

Becker, F. and Steele, F.(1995) *Workplace by Design, Mapping the High-Performance Workscape*, Jossey-Bass Inc. San Francisco, USA.

Davis, G. (1986) *Building Performance: Function, Preservation, and Rehabilitation*, ASTM STP 901, Philadelphia, USA.

Davis, G., et al. (1993) *Serviceability Tools: Volume 1 -- Methods for Setting Occupant Requirements and Rating Buildings; Volume 2 -- Scales for Setting Occupant Requirements and Rating Buildings; Volume 3 -- Generic Requirement Packages (in progress); Volume 4 -- Requirement Scales for Office Buildings (excerpt from Volume 2); Volume 5 -- Rating Scales for Office Buildings (excerpt from Volume 2)*, The International Centre for Facilities, Ottawa, Canada.

Davis, G. et al. (1985) *ORBIT-2 Main Report and Supporting Volumes*, Harbinger Group Inc., Norwalk, USA.

Davis, G. and Ventre, F. T. (1990) *Performance of Buildings and Serviceability of Facilities*, ASTM STP 1029, Philadelphia, USA.

Eley, J. and Marmot, A.F. (1995) *Understanding Offices, What every manager needs to know about office buildings*, Penguin Books Middlesex.

ISO (International Organization for Standardization). *ISO 9000 Compendium – International Standards for Quality Management, 4th Edition* (ISO, Central Secretariat, Genève, Switzerland, 1994).

Steele, F. (1986) *Making and Managing High-Quality Workplaces*, Teacher College Press, Columbia University, New York City, USA, and London, UK.

Szigeti, F., Davis, G., Atherton, A., and Henning, D. N. (1997) *Changes in the Relationships between Customers and Providers of Facilities, and Usefulness of the new ASTM/ANSI Serviceability Standards for the Procurement of Office Facilities*, in Proceedings, CIB W92 Symposium, Montreal.

End Note: Figures 1, 2, and 3 are included with permission from the International Centre for Facilities, Ottawa, Canada.

178 BUILDING PERFORMANCE STARTS AT HAND-OVER: THE IMPORTANCE OF LIFE SPAN INFORMATION

M.H. Hermans

Damen Consultants, Rotterdam, The Netherlands

Abstract

Life cycle information is regaining attention throughout the building industry, and in particular among those involved in managing the existing building stock. Due to the increasing attention for the performance concept in building, for sustainable building and changes in maintenance policies, the importance of reliable life span information is felt by more people. Life span information is necessary to support investment decisions and to calculate the environmental impact of buildings and building components. Life span is an ambiguous term, however. It can be interpreted in many different ways. So what kind of information are we looking for?

Keywords: Performance concept, performance over time, life spans of building components, sustainable building, building use

1 Introduction: The performance concept in building

Due to a changing real-estate market, the building sector has to become more "consumer-oriented", in line with other industries. In Western Europe the post-war quantitative need for buildings, both dwellings and offices, is more or less fulfilled. The demand is concentrating on quality aspects. The market is changing from supply driven to demand driven. The building has to fulfil user requirements. The user requirements contain a mix of building regulations, social and cultural standards and specific, individual requirements set by the building owner and user. Communication should include information on the performance of the building in relation to these requirements and should pay attention to changes in either requirements or the performance supplied by the building. Communication on buildings should be using terminology, which can be understood by the customers: the occupants and building owners. It should focus on the use of the building rather than on technical issues.

Durability of Building Materials and Components 8 (Volume Three). *Edited by M.A. Lacasse and D.J. Vanier*. Published in 1999 by NRC Research Press, Ottawa ON K1A 0R6, Canada. ISBN 0-660-17742-0

These developments are in line with the ideas of the performance concept in building. A building is considered to be a functional product with a performance, rather than a combination of technical components.

So far, attention has been paid primarily to the performance of a building at hand-over. At that moment – or a few months afterwards – the building team is officially dismissed and the building process is deemed to be over. For the building owner and user, the process only starts at that moment. For them, the performance at hand-over is only the beginning. After the building is taken into use, its performance will change continuously under the influence of climate, use, maintenance and the quality of the building itself. The building owner and user have to deal with this performance over time. If insufficient attention has been paid to the performance over time in the design and construction process, considerable efforts may have to be made to keep the building in shape afterwards.

In a consumer-driven market, the attention for the building performance over time will grow. This explains for instance the increasing research into performance and maintenance contracts. In maintenance contracts, parties (such as the building manager and a maintenance contractor) agree on a performance level to be maintained over the contracted period.

The attention for building performance over time supports an increasing awareness of life spans: When can the building performance be said to be ended or, in other words: when does the building or building component's lifetime end?

2 Life span in relation to performance and requirements

In general, the life span of a building component can be defined as the period a building component can fulfil its requirements. Unfortunately, both the performance of the component and the requirements change over time. Depending on the type of change, the life span of a product will be longer or shorter (figure 1).

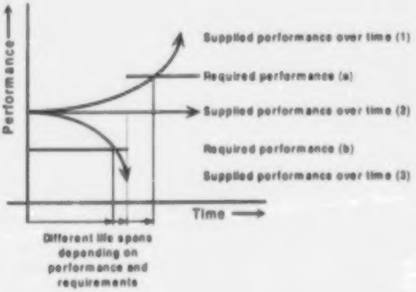

Performance
Supplied performance over time (1)
Required performance (a)
Supplied performance over time (2)
Required performance (b)
Supplied performance over time (3)
Time
Different life spans depending on performance and requirements

Fig. 1: Some examples of the life span of a component in relation to its performance and requirements

Building owners and users are looking for ways to agree on the period a building or component will deliver its performance, and the minimum performance supplied during this period (figure 2).

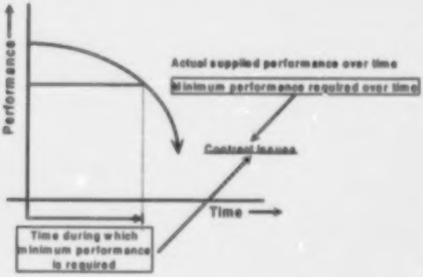

Performance
Actual supplied performance over time
Minimum performance required over time
Contract issues
Time
Time during which minimum performance is required

Fig. 2: Agreements on minimum performance over time and minimum life span

3 Application of life span information

Life span information can serve several goals in the different phases of a building's life cycle:

- Choosing between alternative building components;
- Calculating exploitation costs of alternative buildings;
- Long term maintenance planning;
- Determining depreciation periods;
- Calculating the environmental impact of components.

Life cycle information indicates when a component should be replaced. This information is useful when setting budgets for the exploitation of a building. If the expected period of use of a building as a whole is given, the life spans of the composing parts of the building can be attuned to this expected time of use.

Life span information also indicates when maintenance activities are necessary. Traditionally, building management focussed on minimising short term maintenance costs. Currently a change can be seen towards optimising maintenance in relation to organisational goals and means in the middle and long term. The maintenance sector shows a transition from technical aspects to functional aspects. The "why" of building maintenance is becoming a focal point: which objectives does an organisation have for its buildings, and which are the budgets available for realising those objectives? Maintenance is seen as one of the means to manage real estate, next to for instance buying and selling and refurbishment.

The new generation of maintenance systems explicitly takes the required performance into account in planning maintenance activities. The earlier generation centred on what was technically needed to restore a building in an acceptable condition. The condition aimed at was more or less fixed. The new generation adjusts the condition aimed at, to the organisational objectives. Attuning maintenance activities to requirements asks for information on the intended period of use as well: if requirements change, the maintenance activities should be adapted.

4 Sustainable building

Until about ten years ago, the term "durable" meant "to last as long as possible". The meaning of the word has changed, however, to "fulfilling the set requirements for as long as those requirements exist and with minimal environmental impact". The term has therefore become more complex and specific. To indicate this transition and to prevent misunderstanding, the word "durable" is nowadays often replaced by the word "sustainable".

According to the definition, sustainable building implies that the requirements of future building users are known. It also implies that the duration of the requirements is known. And on top of that, the requirements have to be answered in a way that the effects to the environment are minimised. The solution found will always be based on the existing state of the art in building technology. Meaning that the knowledge of the actual environmental impact of a product and the production means available, change over time.

The period of use of a product, indicating the time elapsing before a product is being disposed of, is an important parameter in the determination of the environmental impact of the product. The environmental impact is proportional to the period of use. Reliable life span information is essential in reviewing the durability (or "sustainability") of a building or building component.

5 Types of life spans

For manufacturers, life span information can be a competition item: They will try to present their product in the most favourable way. Agreements are therefore necessary, on how the life span of a product should be determined and presented. First of all, it should be clear what is meant by the word "life span". Depending on the perspective, "life span" can be defined as, for instance, "time of existence", "period of use" or "depreciation period". When giving life span information, it is of the utmost importance to indicate which perspective is represented. The most important types of life span are the technical life span, the functional life span and the economic life span.

5.1 The technical life span

The technical life span in its most limited meaning, stands for the time that a product physically exists. Of course, the concept of "physical existence" should be specified: Masking weak spots or leakages can prolong the life span of a bituminous roof cover. At what stage of deterioration is the life span of the roof considered to be ended? In other words: how many repairs are acceptable and when should replacement be considered? As the technical life span will rarely be used completely, the precise determination of the technical life span of components is not of interest to the building owner or user. Agreements can be important, though, in relation to the determination of environmental impact.

In daily practice, the technical life span is considered to be the period that a building component can physically supply the required performance. In the Netherlands, the Building Research Foundation (Stichting Bouwresearch) publishes a report called "Life spans of building components. Practice-based values."

When determining the technical life span it is important to define the circumstances in which the life span will be reached precisely. The technical life span strongly depends on the materials used, detailing, building location. The intensity and type of use and maintenance also play an important role. "The" technical life span therefore does not exist. It is always a life span under specified conditions. Unfortunately, sufficient knowledge on the impact of these conditions is still lacking. As the number of factors is huge, empirical life span research is costly and complex.

5.2 Period of use

The period of use or functional life span of a building component is the life span the building component is actually used. The question is what type of use is still considered to be functional? If a door is used as a tabletop, is this form of use included in the "functional life span" or not? If it is, how can future applications be foreseen at the moment a building component is put on the market? The type of use should be indicated to be able to set a functional life span. At the other hand, as long as a building component can have a function, regardless of the type of function, it will not be disposed of. This is in favour of the environment and re-use for other functions should therefore be taken into account in determining the period of use for environmental calculations.

From a practical viewpoint, the functional life span is defined as the period a building component can fulfil the function for which it was originally made. Re-use (for the same function) and high or low level recycling possibilities should be indicated. In the current building practice, information on the actual, real-life periods of use of building components is still lacking almost completely.

5.3 Economic life span

The economic life span is the period that no alternative exists with lower or at least equal exploitation costs for a building component. The subject for debate is the comparison of the equality of alternatives. Technological developments are not on hold during the building's use. Therefore new and improved products will become available during a product's life cycle. Components are therefore hardly ever replaced identically. In nearly all cases some kind of performance improvement will be realised as well. This improvement should be accounted for in determining the economic life span of a building.

The economic life span and environmental requirements can be on bad terms: replacement for economic reasons may not be very sustainable, unless the environmental impact of replacement is translated into costs and included in the price of the alternative.

If a component is being replaced by a more environmental friendly component, the environmental impact of replacing a still-functioning component and the profit in terms of prevented environmental impact caused by replacing the old component, should be weighed against the impact of the new component.

6 Life spans and building components

There is a relationship between the type of building component and the type of life span most relevant to the component:

- For structural parts the technical life span in general is endless. Their life span depends on the period of use of the building as a whole. Usually, a fictional life span is set for those components, for instance 75 years. This number does not indicate the real period of use, but is an endpoint of a planning horizon, for instance in maintenance plans. The actual period of use (until demolition) of buildings usually is a lot longer, in the Netherlands approximately 100 years.
- For external building components, such as the facade and roof, the life span strongly depends on maintenance activities. The life span of the component is "technical" and is related to the design, use and maintenance of the component. For office buildings there can be a different situation, if for instance the image of the facade is important and replacement of the facade is induced by the need for a aesthetic face-lift, rather than deterioration of the facade components.
- User appreciation and the primary processes of the user organisation determine the life span of interior components. If there are changes in the way the building is used or if the taste of the building user changes, components are being replaced. Functional criteria, rather than technical criteria determine the life span.
- The life span of building services nowadays strongly depends on technological developments. Automation of building services causes obsolescence due to outdated software, before any technical deterioration of the apparatus itself can occur. Also changes of regulations can cause an early end of lifetime, for instance if energy regulations are tightened.

Life span information of building components should represent the above most important reasons for replacement. The components should be designed in a way fitting the life span: their technical life span should be attuned to the functional and economic life span. If a component will be replaced often, for instance due to rapid changes in fashion, the connections of the component should facilitate easy replacement. Components with a life span as long as the building's period of use, can have more fixed connections.

7 Conclusions

Life span is a complex term with many different interpretations, differing from mere "time of existence", to "period of use". Life span information is needed to support decisions relating to investments in new or existing buildings and to calculate the environmental impact of components and buildings in order to make sustainable decisions in planning, designing and upkeeping the building stock. Agreements are necessary between those offering life span information and those using life span information on what interpretation of the word life span is relevant in a particular situation. This paper indicates the different types of life span which may be worthwhile discriminating between. The type of life span relates to the reason why a component is being disposed of. This can be for technical reasons (the component is not able to perform any longer), for economic reasons (there are products on the market with a better price / quality ratio) or for functional reasons (the demand is changing and the component can not fulfil the changed requirements).

When designing a building, the most likely reason for replacement of the individual components should be assessed. Then the moment when the replacement will take place should be estimated, based on practical experiences with similar components in other situations. This actual, practice-based period of use should be the starting point for environmental calculations.

8 References

Hermans, M.H. (1995) *Deterioration Characteristics of Building Components. A data collecting model to support performance management*, Ph.D.-thesis, Eindhoven University of Technology

Hermans, M.H. (1998) Sustainable Building Maintenance, in: *Proceedings CIB World Building Congress 1998 "Managing for Sustainability – Endurance Through Change*, Symposium D, pp. 1863-1870, Gävle, Sweden, ISBN 91-630-6711-0

Hermans, M. (1996) *Possibilities for extending the guaranteed life span of building products*, (in Dutch), Damen Consultants, Report for the Dutch Ministry of Housing and the Ministry of Economic Affairs, Rotterdam

Huffmeijer, F. (1995) Life Span of building products. Practice-based figures, (in Dutch), SBR publication 355, Rotterdam, ISBN 90-5367-162-5

Hermans, M. (1998) *Life span clauses in performance contracts* (in Dutch), Damen Consultants, Report for SBR, Rotterdam

*NOTE: The author is changing position, from Damen Consultants to KPMG Management Consultants, starting 1 January 1999.

179 MANAGING THE LIFE CYCLE REQUIREMENTS OF FACILITIES

P. Huovila

VTT Building technology, Espoo, Finland

Abstract

This paper describes a formal approach to manage the life cycle requirements of facilities. Two tools are used to support the performance approach and to make sure about the serviceability of the building. Firstly, Quality Function Deployment (QFD) is utilised to agree on project and design objectives. Secondly, a Requirements Management system (EcoProP) still under development and experimental implementation is applied to assure that the user requirements are met. These tools are used in two different research projects that have environment-friendly objectives as their common nominator.

Keywords: Life cycle design, performance approach, requirements management

1 Introduction

Construction is an old discipline and still very much practice-oriented. End products of construction, buildings, that have been traditionally considered to have value as such, may be today judged from a completely different view. Construction can be seen a process that provides, together with other processes, services to the users of facilities. In other words: to serve others' needs and expectations and not to produce something from its own aspirations. Or, construction may be seen as one of those processes that offer assets to investors and speculators. The owner's expertise is to rate the profitable life span for the investment. That is usually far shorter than the service life of the building, its materials and many of its components.

In both cases, the serviceability of the built facility is essential. More important than knowing how the building is constructed and which are the products used is to know how well it will perform during its service life. And how well it can adapt to

Durability of Building Materials and Components 8 (Volume Three). *Edited by M.A. Lacasse and D.J. Vanier.* Published in 1999 by NRC Research Press, Ottawa ON K1A 0R6, Canada. ISBN 0-660-17742-0

the changing needs of its users and owners. The judgement of the serviceability of the facility must be obtainable at any given moment. It is a weak argument to justify a refurbishment investment or a heavy demolishing need by saying that the values were different at the time when the decision was made to construct the present performances. And that the investment was then considered advantageous.

Different tools and techniques can be applied to protect oneself against tedious surprises, such as performance prediction and risk assessment (Lounis et al. 1998). This paper discusses findings from implementing the performance concept and experiences from two tools that support the approach: Quality Function Deployment QFD (Akao 1990) and Requirements Management (Huovila and Serén 1998). Both of them have been experimentally piloted in building design processes aiming at serviceable facilities during their life span.

2 The performance approach

Some well-identified problems related with the design process can be listed:

- how to understand what the client really needs and what can be achieved
- how to interpret and to express the needs in a form of requirements
- how to verify that the design is conform with the requirements
- how to execute the design in a productive and qualitative way.

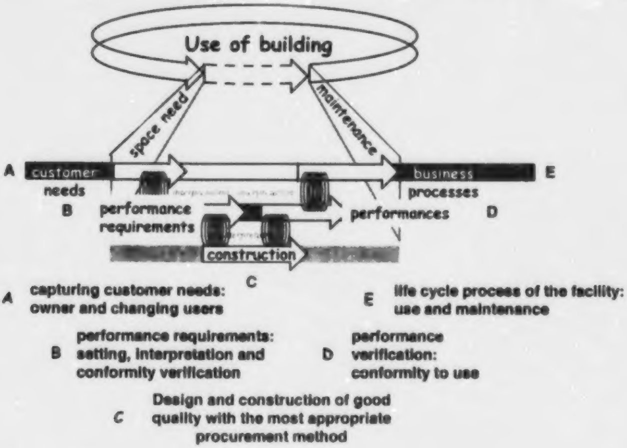

Use of building
space need
maintenance
A
customer
needs
B
performance
requirements
construction
C
business
processes
E
performances
D
A capturing customer needs: owner and changing users
E life cycle process of the facility: use and maintenance
B performance requirements: setting, interpretation and conformity verification
D performance verification: conformity to use
C Design and construction of good quality with the most appropriate procurement method

Fig. 1: The performance concept

Findings from a preliminary study in Finland were that the performance approach forces the clients to think what really is needed to support their business processes. The identified potential advantages of the approach were that it helps benefiting the suppliers' expertise, it moves the design emphasis earlier in the project, improves communication between different partners, enables competition between different technical solutions based on same performance specifications. It should also lead to profitable product development and facilitate the clients to obtain products that meet their needs. It also means that more effort is needed for the early phases of design. It may require changes to the traditional working procedures, new competition modes and agreements, maybe even definition for a new language and certainly increased communication along the design process.

3 Setting the objectives and achieving the team commitment

Quality Function Deployment (QFD) is a tool that has been successfully applied as a product development tool for consumer products. It offers a systematic approach to match the customer expectations with the features of the product, and to document the decisions in the design process. QFD can be seen as a team decision making tool to achieve common understanding and commitment to design objectives and prioritised characteristics of the design solutions. It is well known in the development of consumer products, but in the construction practice its known implementations (Huovila et al. 1995) are few.

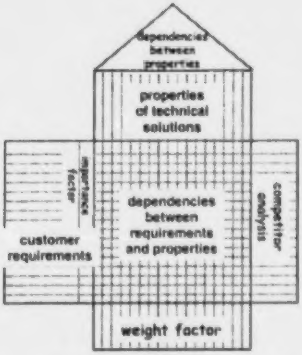

dependencies between properties
properties of technical solutions
importance factor
customer requirements
dependencies between requirements and properties
competitor analysis
weight factor

Fig. 2: The structure of the QFD house of quality matrix

QFD was recently experimented in an afternoon brainstorming session to set design guidelines together with ten experts of different backgrounds for a prototype building to be developed for a Housing Fair. That exercise had the following objectives:

- to share common understanding of the performance-based objectives
- to prioritise the project objectives
- to strive for innovative design solutions that meet the prioritised project objectives.

In this case, the tool was found useful to structure the meeting. In addition, it provided a way to document the decision path. It also enabled recording innovative solutions that were not selected for that project, but have potential to be further developed in other occasions.

VTT	PHASE I Properties	M	T	S		T	V	V			S		TOT		V	A	M	M				
	Requirements	adaptability	resale value	indoor conditions	attractiveness	economy	autonomy	friendliness to the environment	futurity	habitability	respond to the environment	good indoor climate	constructability	identity	local ecology	architecture	[illegible]	recyclable for house	transferability	dismountability		importance/weight factor (P1)
functionality	Utiliseability	9	9	9	9	3	9	3	0	9	0	9	9	1	1	9	9	3	1	0		5
	Adaptability	9	3	9	9	3	1	9	3	9	0	0	1	1	9	9	1	9	9	9		2
	Maintainability	3	3	3	3	9	9	9	0	9	0	3	9	0	9	1	3	1	1	1		2
environmental	Operation	9	3	9	3	9	9	9	1	1	9	9	9	0	9	9	0	0	0	0		4
loading	Construction	9	9	9	3	3	0	9	0	0	0	0	9	1	9	1	0	9	9	9		2
resource	Energy	9	3	9	3	9	9	9	9	0	9	9	9	3	9	9	0	1	1	1		5
use	Water	9	1	9	1	3	9	9	3	1	0	0	9	0	3	9	1	0	0	0		1
	Materials	3	9	9	3	9	1	9	9	9	0	9	9	9	9	3	0	9	9	9		1
life	Investment costs	9	9	3	3	9	3	9	0	0	3	3	9	1	0	9	1	3	3	3		3
cycle	Operating costs	9	9	1	3	9	9	9	3	0	3	1	9	3	3	9	9	3	3	3		4
cost	Maintenance cost	9	9	3	9	9	9	9	9	0	9	3	9	3	3	9	3	3	3	3		2
indoor	Acoustic comfort	9	9	9	9	9	0	9	9	9	0	0	3	3	0	9	0	0	0	0		2
quality	Thermal comfort	9	9	9	9	9	0	3	9	9	9	9	3	3	0	9	3	0	0	0		3
	Lighting	9	9	9	9	3	9	3	9	9	9	0	3	9	1	9	1	0	0	0		4
	Indoor climate	3	9	9	9	9	0	3	9	9	9	9	9	9	1	9	0	0	0	0		5
architecture	Architecture	9	9	9	9	9	3	9	9	9	3	0	9	9	0	9	1	3	3	3		3
	Weight factor (P1)	383	355	322	307	285	273	258	250	248	246	241	182	180	179	169	118	112	102	97	0	4317
	Weight factor %	9 %	8 %	7 %	7 %	7 %	6 %	6 %	6 %	6 %	6 %	6 %	4 %	4 %	4 %	4 %	3 %	3 %	2 %	2 %	0 %	100 %
	Votes	4	1	3		2	1	3			1		2		4	4	1	1				
	Selected	X		X		X		X					X			X						

Fig. 3: Prioritising the design objectives in a QFD process

In the QFD process different teamwork techniques can be used to identify the requirements (matrix rows) and their weighting (importance factor values 1...5). Correspondingly the product properties (matrix columns) and their dependencies to the requirements (matrix cell values 0, 1, 3, 9) are filled in the matrix. The next step is to take advantage of the calculated weight factors (at the bottom of the matrix) to facilitate the selection of the properties (x) that will be emphasised in that project.

The participants' feedback from the QFD experiment was positive. The half-day session resulted in two QFD House of Quality Matrices that were delivered to them as paper prints at the end of the day. The process led to identification of some new design objectives and innovative solutions. The results did not conflict with the earlier objectives. The selection was unsurprising as judged afterwards. On the other hand no one can tell where another kind of process would have led.

Later on Quality Function Deployment tool will be tested as a trade-off analysis tool in design process as a part of the ongoing in the IEA task 23.

4 Describing the properties of building

Managing the serviceability of buildings requires control over the properties of the building systems and building parts. Various master lists, checklists or classifications of requirements or properties of buildings have been developed by CIB (1993), ISO (1984), EC (1989) or GBC (Nilsson 1998).

ISO6241 User Requirements

- Stability
- Fire safety
- Safety in use
- Tightness
- Hygrothermal
- Air purity
- Acoustical
- Visual
- Tactile
- Dynamic
- Hygiene
- Suitability of spaces
- Durability
- Economic

CIB Master List of Properties

- Capacity, consumption
- Structural, mechanical
- Fire
- Gaseous, liquid, solid
- Biological
- Thermal
- Optical
- Acoustic
- Electric, magnetic
- Resistance to attack
- Service life, reliability

EC Essential Requirements

- Mechanical resistance, stability
- Safety in case of fire
- Hygiene, health and environment
- Safety in use
- Protection against noise
- Energy economy and heat retention

Green Building Challenge 98

- Resource consumption
- Environmental loadings
- Quality of indoor environment
- Longevity
- Process
- Contextual factors

Fig. 4: Checklists of properties or requirements

5 Managing the requirements

A Requirements Management System, EcoProP, was developed to help the clients to express their sustainability objectives in a concrete and measurable way. The system is based on a list of generic properties that can be classified in three categories:

- performance characteristics: conformity to business processes, location, indoor conditions, service life and deterioration risk, adaptability, safety, comfort and loading to immediate surroundings
- characteristics of the properties: life cycle costs, environmental burdens in operation and embodied environmental loading in building parts
- process issues that do not relate with the building in use, but during the construction phase.

EcoProP is currently piloted in four live projects emphasising at indoor conditions, service life and deterioration risks, adaptability and environmental burdens in operation. The objective is to express the higher level characteristics at a lower level in a form of concrete values or classes that are set as design objectives in environmentally friendly building projects. The requirements are documented and the corresponding verification methods are cited when possible.

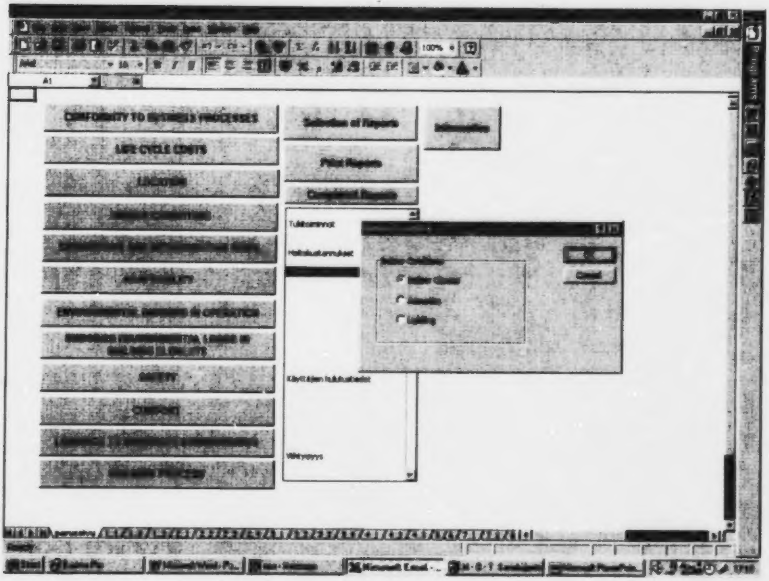

A1
100%
CONFORMITY TO BUSINESS PROCESSES
LIFE CYCLE COSTS
LOCATION
SAFETY
COMFORT
Selection of Reports
Print Reports
Completed Reports
Information
Ready

Fig. 5: The EcoProP user interface

6 Discussion

Formal methods and systematic procedures are still not everyday practice in construction. Most promising benefits of the described tools will most likely be achieved in cases where competition is emphasised at the qualities of the end product and innovation is encouraged. The customer-oriented approach may require some additional time compared to production-driven approach, but the gains from better serviceability of facilities, higher customer satisfaction and longer partnership relations should bring the balance.

7 References

Lounis, Z., Vanier, D. and Lacasse, M. (1998) Effective decision-making tools for roofing maintenance management. *Proceedings of the First International Conference on New Information Technologies in Decision Making in Civil Engineering*, Montreal, October 11-13. pp. 425-436.

Akao, Y. (1990) *Quality Function Deployment QFD, Integrating Customer Requirements into Product Design*, Cambridge. MA, Productivity Press.

Huovila, P. and Seren, K.-J. (1998) Customer-oriented design methods for building design. *Journal of Engineering Design*, Vol. 9, No.3, pp. 225-238, Carfax Publishing Ltd.

Huovila, P., Lakka, A., Laurikka, P. and Vainio, M. (1997) Involvement of customer requirements in building design, in *Lean Construction*, (ed. Alarcon, L.), A.A. Balkema, Rotterdam, pp. 403-416.

CIB (1993) *CIB Master List of Headings for the Arrangement and Presentation of Information in Technical Documents for Design and Construction*, CIB Report, Publication 18.

ISO (1984) *Performance Standards of Buildings, Principles for their Preparation and factors to be Considered*, ISO6241.

EC (1989) *The Construction Products Directive.*

Nilsson, N.K. and Cole, R.J. (1998) GBC '98: Context, history and structure, in *Green Building Challenge '98 Conference*, Vancouver, October 26-28, pp. 15-25.

180 WHOLE LIFE PERFORMANCE STRATEGY: BEYOND INCREMENTAL COST AND SERVICE LIFE

D.P. Rowe

Agile Construction Initiative, University of Bath, UK

Abstract

The cost comparison of component and product options is an essential aspect of design, construction, operation and maintenance. But there is a case for looking beyond incremental costing to embrace socio-environmental and business impacts. Decision-making has included these wider impacts where a financial proxy has been developed or to satisfy legislative requirements or appease project opposition. There is, however, no clear and comprehensive contemporary strategy to integrate with a whole life appraisal those issues that do not easily align themselves with economic description. The basis of UK construction industry decision-making is reviewed to establish the range and influence of whole life performance issues. Shortcomings are identified in this process and it is argued that, in order to achieve improvement in whole life performance, there is a need to reform the scope of decision-making. A case is put forward to achieve this by explicitly considering performance from multiple perspectives. It is recommended that discounted cash flow analyses are supplemented by the development and application of a multi-perspective performance model. Current industry organisation plays a key role in failing to motivate broad whole life appraisal. Procurement arrangements typically lack incentives for construction industry participants to concern themselves with whole life issues. Where whole life issues are addressed, much emphasis is placed upon service life, deterioration, and repair and maintenance interventions. These are important and their prediction is still raising many challenges. But genuine functional value and issues associated with greater levels of uncertainty and risk such as technological innovation, obsolescence, sustainability and procurement efficiency should not be marginalised owing to difficult prediction. There is a need for professional project participants to think in terms of a softer interface between disciplines and to engage issues traditionally regarded as immovable or outside their remit.

Keywords: asset management, whole life performance, life cycle costing, service life, value management.

Durability of Building Materials and Components 8 (Volume Three). *Edited by M.A. Lacasse and D.J. Vanier*. Published in 1999 by NRC Research Press, Ottawa ON K1A 0R6, Canada. ISBN 0-660-17737-4

1 Introduction

Construction industry protagonists have a long history of artfully resolving the technical complexity of marrying natural and manufactured materials. Civil engineering in particular has been portrayed as an art because practitioners have been expected to operate within an environment made uncertain by dealing with nature and by making allowances for gaps in knowledge and information. Decision-making has therefore relied heavily on individual experience.

Whilst the ability to base decisions on partial information and from individual experience may have proved a strong and sufficient characteristic in the past, the emerging expectation of predictable, efficient and safe construction (DETR 1998a) demands an increasingly structured approach. Such expectations are concerned with the role that construction has to play in serving the immediate needs of asset creation and management. They are being addressed through a variety of initiatives including that of the Agile Construction Initiative (ACI)[i] of which the research for this paper forms a part. But these immediate needs are supplemented by an increasing emphasis on infrastructure management driven by long term objectives of sustainability (DETR 1998b), service (DETR 1998a) and hence value.[ii] The developing importance of these objectives is affording a growing significance to the recognition of Whole Life Performance (WLP).

The issues, solutions and conclusions discussed within this paper are applicable to construction generally. Many authors, however, due to the wide and varied scope of life cycle issues, have written on WLP in connection with specific sectors and with respect to specific problems within sectors. In keeping with the initial application of the ACI to the roads sector, many of the arguments in the proceeding discussion are supported by references within that sector. Similarly, the proposed approach to WLP that leads beyond incremental cost and service life is illustrated within the context of trunk road management.

2 What is whole life performance?

The key principle distinguishing WLP from the majority of appraisal effort is the consideration of project impacts for more than just the imminent single project phase (such as initial construction or refurbishment). WLP is used, within the context of this paper, to represent the securing of efficient long-term value via the appraisal of impacts occurring throughout the project life cycle. WLP is discussed in the context of the widest possible scope of issues influencing the value obtained from asset management (an intentional strategy to avoid pre-determining important issues). WLP is considered a description for the holistic management of infrastructure. It is not prescriptive, but serves as a conceptual framework within which a system of conventional models can be applied.

---

[i] The Agile Construction Initiative was established at the University of Bath in 1996 to investigate and promote the application of lean manufacturing principles to construction.

[ii] The definition of value is case-specific, but is generically determined within lean manufacturing as that "which meets the customer's needs at a specific price and a specific time." (Womack J, Jones D, Lean Thinking, 1996)

Various terms have been applied to the assessment of the long-term consequences of asset management decisions.[iii] Terms do not appear, however, to correspond to a universally agreed scope, and many of the terms overlap in definition. Life Cycle Costing (LCC) has been quoted, for example, as *"total cost of an item throughout its life, including the cost of planning, design, acquisition, operations, maintenance and disposal, less any residual value."* (BSI 1997). But many definitions of LCC have been proposed (Woodward 1997} and, because it is often used to represent Investment Appraisal, the scope of LCC often incorporates benefits as well as costs (Ferry and Flanagan 1991). What emerges, however, is a polarisation of analysis between financial modelling and socio-environmental statement. It is proposed that WLP is represented by models providing equal representation across the range of socio-environmento-economic issues.

3 Why is an understanding of whole life performance important?

The profile of WLP is rising in some non-UK construction sectors. The Victorian government in Australia has placed WLC for construction projects exceeding A$5m on the legislature (Graves et al. Unpublished). Legislation[iv] in the USA has taken this still further with mandatory LCC consideration for all federal transport infrastructure projects (Markow 1995; Bettigole 1995). The important potential strategic role of WLP has already been recognised to varying degrees in sectors outside construction including the oil, automotive and aerospace/defence.

UK Construction industry attitudes towards an increased consideration of whole life issues are changing. A strong awareness by client and supply sides of the importance of whole life issues has been confirmed by recent studies (Clift Forthcoming; Graves et al. 1998). WLP is important as it can drive value-added construction products and reduce construction defects (Rigden et al. 1995), drive value-added construction design (Leeming 1993; Markow 1995; Wallbank and Lickiss 1990) and, as suggested from experience in the oil industry, facilitate ideas and reduce reliance on conventional wisdom (Harding 1996). The need to investigate the long-term implications of decision-making has been reinforced by many factors exemplified in the UK public sector by year on year reductions in funding availability (Leadbetter 1996).

Contractors and suppliers have traditionally retained a phase by phase involvement with construction projects. But the last five years has seen the client-driven Private Finance Initiative (PFI)[v] introduced to re-distribute many of the root causes of poor project value, including short-term responsibility. Two of the intended benefits arising from PFI schemes are minimised lifetime costs and "Whole Asset Life" benefits (Treasury Taskforce 1997).

[iii] These include Life Cycle Costing, Life Cycle Cost Analysis/Assessment/Management, Whole Life Costing, Life Cycle Assessment, Environment Impact Assessment, Whole Life Performance and Cost-Benefit Analysis.

[iv] The Intermodal Surface Transportation Efficiency Act (ISTEA) was introduced in 1991 to mandate "the use of life-cycle costs in the design and engineering of bridges, tunnels, or pavement." This was supplemented in 1994 by an Executive order that requires "a systematic analysis", considering "design standards that incorporate new technologies and construction techniques."

[v] The UK PFI represents a culture change in public sector procurement where the public sector role of asset owner and direct service provider is transferred to being a purchaser of those services from the private sector.

A commitment to appraise WLC by representatives from both client sectors has been made by the Construction Clients' Forum (CCF 1998). This acknowledges the client's role in developing long-term cost-effective construction.

4 Shortcomings of whole life performance in contemporary application

4.1 A commitment to financial modelling

Whole Life Costing (WLC) is commonly used to describe financial modelling for WLP. The definition for WLC proposed by the Construction Research and Innovation Strategy Panel (CRISP) is *"the systematic consideration of all relevant costs and revenues associated with the acquisition and ownership of an asset"*. (DETR 1998c). Discounted Cash Flow analysis (DCF) is the technique used to model the temporal distribution of costs and revenues for WLC. DCF provides an investment appraisal technique to undertake budgetary planning. It utilises a cost of capital to provide a discount rate, allowing future cash liabilities to be expressed in terms of present values and therefore allowing comparison of investment options in terms of a single present value. Hence economic appraisal provides an objective ranking method for decision-makers. It is, however, limited by the adequacy of financial model, and it poorly communicates the socio-environmental consequences of proposals.

In the UK, and many other countries, a single public sector discount rate is universally applied (Rigden et al. 1995). A high public sector discount rate has been cited as a barrier to the construction of long life, low maintenance infrastructure (Leeming 1993), the converse applying with a low discount rate (Tilly 1997). Discount rates are seen to be highly influential to maintenance policy (Vassie 1998; Singh 1996). The effect of typical discount rates feature prominently in the assertion that DCF is relevant mainly to assets requiring frequent maintenance and with relatively large operating costs (Ferry and Flanagan 1991). This position has been directly opposed by examples of civil infrastructure (Leeming 1993), and further evidence is available from both the public (Treasury 1992) and private (Owen 1995) sectors that supports DCF evaluation over a 25 year period.

It is inevitable that discounting will reduce the benefits accruing from options requiring low future expenditure levels. A widely expressed opinion is that, whilst WLP is considered very important, the solutions supported by DCF-led WLC often do not coincide with the solutions intuitively considered best by those involved in their development. This is exemplified in bridge management where it has been shown that considerably different strategies typically show only a small difference in present values (de Brito and Franco 1994).

Whilst a case could be argued for the development of project-specific discount rates, this fails to address the issue that financial models are generally inadequate for comprehensive project or strategy appraisal. Difficulties with economic evaluation of socio-environmental effects are well recognised (Mishan 1988a). And it has been argued that a traditional insistence on economic argument is probably less effective than argument based on quality of life issues (based on current financial models) to support transport infrastructure investment (Simon 1996). Indeed, in global terms, there is growing recognition of the limitations of GDP as the primary indicator of social and economic welfare (The Labour Party). Yet there is a continued emphasis on developing monetary equivalents to socio-environmental effects, where no market mechanism exists, in order to simplify and make more direct the objective comparison of project options (Glendinning 1997; Willis et al. 1998).

Recent studies of both client and supply side representatives found that WLC is not carried out on many projects (Clift Forthcoming; Graves et al. 1998). Respondents confirmed the lack of WLC to result from a number of sources, the most notable of which were: an absence of requirement for WLC; no long-term interest in ownership; insufficient data on WLC; rare monitoring of WLC targets; and lack of a standard approach or methodology for WLC (Clift Forthcoming). The short-term objectives of minimising capital cost and time were quoted as the main decision-making drivers in project procurement. Budgeting arrangements were also found to obstruct developing an interest in long-term performance, more particularly in the public sector but also in the private sector (Graves et al. 1998). This finding supports previous assertions over the lack of a stakeholder link to budget allocation and to project phases as a root cause of apparent client disaffection with WLC (Ferry and Flanagan 1991).

The finding that insufficient data was available on WLC receives mixed support. Sources have cited a lack of maintenance cost (Leeming 1993) and service life (Loudon 1998) data as being a barrier to WLC. Other sources, however, suggest that this may not be the case. Indeed, large information databases have been cited as unnecessary and potentially misleading due to their retrospective viewpoint and tacit implication of the ability to make absolute predictions (Ferry and Flanagan 1991; Markow 1995; Bettigole 1995). It is, however, widely agreed that data does need to be managed through the project phases, providing feedback to close the knowledge loop (Owen 1995).

A picture is thus emerging of widespread problems and disaffection with the financial modelling of WLP (fig.1) as currently practised. Whilst financial modelling plays an important role in determining likely cash flows and estimating returns to shareholders or taxpayers, it does not currently provide a balanced and comprehensive holistic appraisal technique.

4.2 Beyond financial modelling

Conventional financial modelling under-represents issues such as inter-disciplinarity, socio-environmental consequences, obsolescence, long term market productivity, incentivisation, innovation, risk and uncertainty (Markow 1995). New themes including sustainability (DETR 1998b) and quality of service provision are becoming increasingly important, and shareholders and taxpayers are becoming increasingly aware of ethical issues. This wide range of emerging issues, which currently receive highly variable consideration, is driving the need for an holistic decision-making process equipped to take equitable account of issues beyond those currently included in financial models.

The range of shortcomings identified by studies of WLP appraisal implementation (Clift Forthcoming; Graves et al. 1998) provide many of the de-motivating characteristics associated with weak project implementation from a people management perspective. These include: a lack of top-down commitment; ill-defined objectives; constraints on workability; a lack of procedures; and a lack of incentives (Kliem and Ludin 1994). It is, perhaps, not surprising therefore that whole life issues have not been widely implemented in WLP appraisal. It has been noted in the oil industry that, in order for WLP to work, it needs to be championed (Harding 1996). Top-level commitment is required to integrate WLP facilitating processes and techniques into decision-making.

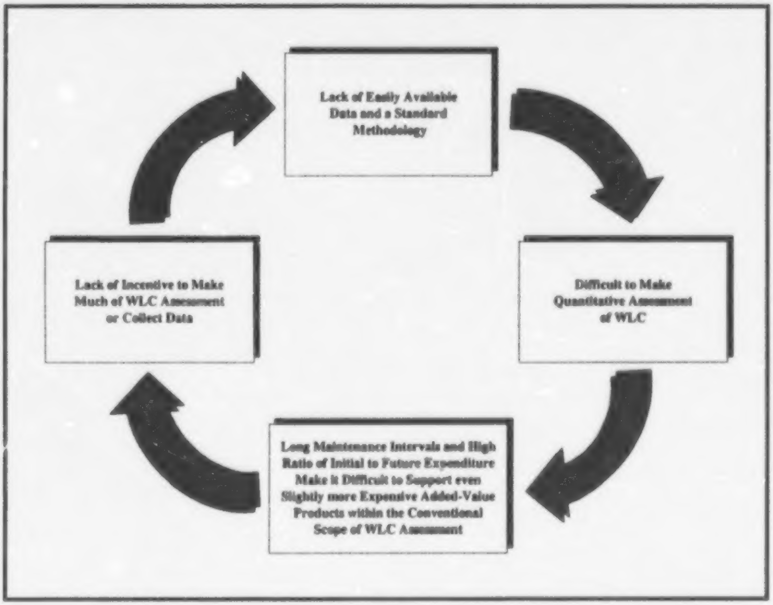

Lack of Easily Available Data and a Standard Methodology
Difficult to Make Quantitative Assessment of WLC
Long Maintenance Intervals and High Ratio of Initial to Future Expenditure Make it Difficult to Support even Slightly more Expensive Added-Value Products within the Conventional Scope of WLC Assessment
Lack of Incentive to Make Much of WLC Assessment or Collect Data

Fig. 1: Perpetuating disaffection with whole life performance

A systematic adoption of WLP is lacking in construction design according to a cross-industry comparison of WLC (Garnett and Owen 1995). This supports the assertion that WLC (constrained by its image as financial 'rubber-stamping') is a marginal activity. Financial modelling can clearly inform the design process, but, to realise the potential of WLP, it needs to be central to the design process. It should form the starting point for the generation of new ideas (Rigden et al. 1995) and a technique to challenge conventional wisdom (Harding 1996).

Experience from industries outside mainstream construction suggests that it is not possible to establish universally applicable models to measure WLP. Risk and uncertainty, central to an examination of WLP, cannot generally be determined by mechanistic forecasting (Proffitt 1994). But there is support for the notion that much can be gained from simple analyses of the problems and by actively developing potential solutions at an early stage across disciplines and through the project hierarchy (Harding 1996). Hence the development of WLP requires the selection of appropriate detailed evaluation models within a universal framework. Much effort has and continues to be devoted to the development of detailed models. The pressing need is to develop and promote a universal framework.

It is proposed that the key requirement to facilitate successful WLP is an appraisal framework that transcends strategic and project levels of decision-making. The framework should facilitate decision-making in the context of the lifetime strategic or project interface with social, environmental and economic well-being. Such a methodology should be amenable to a championed approach.

5 What can balanced scorecards offer to whole life performance?

The Balanced Scorecard (BSC) was introduced by Kaplan and Norton (Kaplan and Norton 1992, 1996) for the monitoring and, later, implementation of organisational strategy (fig 2). It is proposed as a framework for an approach that is both strategic and facilitates devolution to project level, and that achieves both objectivity and balance. It does this through two key features:

- It proposes explicit appraisal from a range of perspectives. This overtly avoids undue focus on any one aspect and avoids the loss of clarity associated with the single step presentation of a balanced judgement. Appraisal based on multiple perspectives offers the potential for objectives to be transferred from strategy to project levels and from client to other supply chain participants.
- It offers the potential to make considerable improvement over traditional appraisals that marginalise aspects failing to be defined adequately in terms of an economic proxy. Environmental and quality of life issues fall into this category, as well as behavioural influences on organisations.

The BSC achieves a whole life perspective by taking a balanced measurement of what has happened and what is expected to happen. It is essential that a discriminating selection of performance indicators is carried out to provide a mix of outcome measurement and performance drivers (so-called lag and lead indicators) (Tsang 1998). A very important message from experience with WLP is that a considerable improvement in WLP is likely to be brought about through the improved management of existing knowledge rather than the development of new knowledge.

Application of the BSC requires the identification of key perspectives from which to view the organisation under scrutiny, together with statements of strategic goals and measures by which such goals may be achieved. Construction is concerned with the development of infrastructure to facilitate social development. The ultimate motivation behind construction is therefore governed by function, and it follows that the ultimate value rests with functionality and not with the products that provide that functionality. Currently in construction there is often an implied link between a specified product and the expectation of functional performance that that product will provide. But, as evidenced by the introduction of PFI, things are changing. Construction client organisations are progressively adopting a shift in emphasis from delivery of products to delivery of services. Evidence that the industry is ready to adopt service performance measures to support strategic goals provides the required opportunity for the application of a BSC approach.

A wide range of procurement types is being used across the industry and within organisations. The absence of clear evidence to promote one system over another (Sheath et al. Forthcoming) means that flexibility in procurement routes is expected to remain for the foreseeable future. Implementation of a BSC approach is valid regardless of procurement system. Indeed, the additional control promoted by a BSC approach may change the balance of argument and lead to an improvement in WLP without the perceived need to transfer long-term responsibility as now with PFI.

The BSC cannot, of course, provide the final answers – the complexity of issues makes this the unavoidable role of decision-makers and follows the assertion that WLP should assist rather than replace rational thought processes (Bettigole 1995). But it does offer a rational and objective framework within which to make those decisions.

6 Application for the highways agency

ACI has established that the treatment of whole life issues for the management of trunk roads has developed and continues to develop via detailed models, but without an effectively communicated underlying strategy. Tools and techniques have developed in response to need. The historically disaggregated organisational structure of highway management has promoted considerable technical development *within* discipline areas. For example, advanced prediction techniques are available for pavement life and are rapidly developing for bridge structures. But there are many problems that obstruct WLP from realising its full potential.

The principal impacts to have been considered to date tend to be examined through a hybrid Environmental Assessment (EA) and DCF analysis (Willis et al. 1998). This separation acknowledges the difficulty of expressing environmental issues in terms of financial proxies, considerable shortcomings having been identified with this type of appraisal (Parrott and Moyes 1997). The outcome is that the DCF incorporates capital works costs with a limited consideration of operating and maintenance works costs. Certain social costs and benefits are also included. Many social and environmental impacts are included via the EA, although this is of limited scope. The impacts identified by the EA tend to be treated as either acceptable or not acceptable rather than with the incremental consideration given to DCF. Some effects are overlooked entirely. Hence the approach has favoured decision-making based on economic optimisation. The DETR has recently developed a new appraisal method for roads to reduce the prominence previously given to monetarised effects (DETR 1998d). But there is ready acceptance that the new approach can probably be refined further and be made more objective, including the introduction of multi-modal comparison (DETR 1998e).

The Highways Agency (HA) manages, maintains and improves the English trunk road network. The HA's business plan (Highways Agency 1998) has been considered in terms of a BSC. It is acknowledged by Kaplan that the four perspectives originally espoused require review to reflect circumstances (Kaplan and Atkinson 1998). Of the four original perspectives, the customer perspective has been split into three to highlight the different requirements of road user, environment and the public. The taxpayer is considered synonymous to the shareholder in the originally proposed BSC. The six-perspective model is shown in fig. 2.

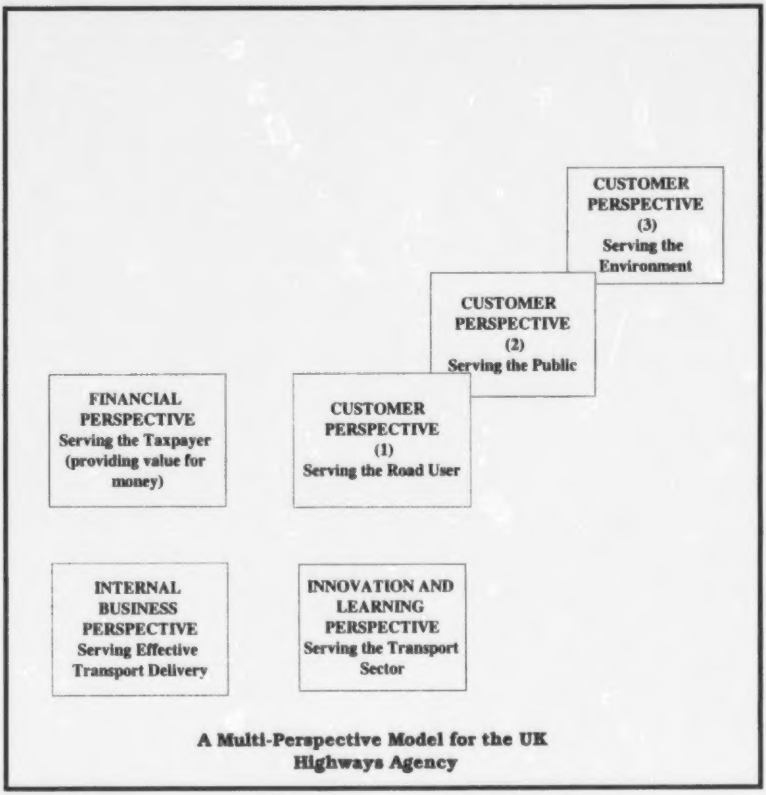

CUSTOMER PERSPECTIVE (3) Serving the Environment
CUSTOMER PERSPECTIVE (2) Serving the Public
FINANCIAL PERSPECTIVE Serving the Taxpayer (providing value for money)
CUSTOMER PERSPECTIVE (1) Serving the Road User
INTERNAL BUSINESS PERSPECTIVE Serving Effective Transport Delivery
INNOVATION AND LEARNING PERSPECTIVE Serving the Transport Sector
A Multi-Perspective Model for the UK Highways Agency

Fig. 2: The balanced scorecard adapted to meet the highways agency's needs

The multi-perspective model offers several potential developments for the HA:

- the demand-led policies followed prior to the creation of the HA[vi] (Halden 1996) provided an emphasis on the road user. The detailed model can provide a visual audit of balance with respect to strategic goals. These can be re-balanced if necessary.
- The strategic goals can be transferred through to project level via the performance measures and targets.
- The project goals with respect to the customer perspectives and, to some extent with the innovation and learning and internal business perspectives, can be transferred from the client to the supply sides via the performance measures and targets. This should promote the demonstration of genuine value (perhaps

---

[vi] The Highways Agency was established in 1994 as an executive agency of the Department of Transport (now Department of the Environment, Transport and the Regions).

providing an objective means of moving towards best value contractor and supplier selection) and create a direct and measurable link between strategic and project level objectives.

7 Conclusions

Considerable effort with developing financial models has failed to provide a satisfactory universal appraisal technique. But the development of WLP appraisal is not simply about being able to forecast with increasing precision the future service life and incremental cost of products. WLP should be a pro-active process of improving value. The BSC approach offers the opportunity to implement WLP.

8 Acknowledgements

The author wishes to record his thanks to M.A.Hall, R.Holt and D.M.Sheath and Prof. C. Tomkins for their assistance with developing this paper.

9 References

Bettigole, N. (1995) Bridge management and life cycle costs. ASCE structures congress proceedings, Apr 3 –5, New York. Vol. 1, pp. 668-669.

British Standards Institution. (1997) Buildings – Service Life Planning Handbook. BSI, London. HB 10141, Part 1, Cl. 3.43.

Clift, M. (forthcoming) Study on whole life costing.

Construction Clients' Forum. (1998) Constructing Improvement: The Clients' Pact with the Industry. University of Bristol, Jan. 1998.

de Brito, J., Branco, F. (1994) Bridge management policy using cost analysis. Proc., Instn Civ. Engrs Structs & Bldgs, Vol. 104, Nov. pp. 431-439.

Department for the Environment, Transport and the Regions. (1998a), Sir John Egan Rethinking Construction: The Report of the Construction Task Force. HMSO.

Department for the Environment, Transport and the Regions. (1998b) Sustainable Development, Opportunities for Change: Sustainable Construction.

Department for the Environment, Transport and the Regions. (1998c) Construction Research and Innovation Business Plan.

Department for the Environment, Transport and the Regions. (1998d) Understanding the new approach to appraisal, Sect. 3, 14 Sep.

Department for the Environment, Transport and the Regions. (1998e) Guidance on the new approach to appraisal, Sect. 1.12-1.14, 14 Sep.

Ferry, D., Flanagan, R. (1991) Life cycle costing–a radical approach. CIRIA Report 122.

Garnett, N., Owen, K. (1995) Life cycle costing techniques: How the construction industry could learn from other industries. COBRA, Royal Instn. Of Chrtd. Srvyrs.

Glendinning, S. (1997) Environmental assessment of highway schemes – a review of DMRB Volume 11. Proc. Instn Civ. Engrs Transp., Vol. 123, May, pp.94-101

Graves, A., Sheath, S., Rowe, D., Sykes, M. Unpublished appendix to the Government Client Improvement Study, HM Treasury, 1998.

Graves, A., Sheath, S., Rowe, D., Sykes, M. (1998) The Government Client Improvement Study. HM Treasury, ISBN 0-947-81961-4.

Halden, D. (1996) Managing uncertainty in transport policy development. Proc. Instn Civ. Engrs Transp., Vol. 117, Nov. pp. 256-262.

Harding, T. (1996) Life cycle value/cost decision making. Proc. of the SPE International Petroleum Conf. & Exhibition of Mexico. pp. 143-152.

Her Majesty's Treasury. (1992) Life cycle costing. Public Competition and Purchasing Unit, Guidance No. 35.

Highways Agency. (1998), Business Plan 1998/99.

Kaplan, R., Norton, D. (1992) The Balanced Scorecard – Measures that Drive Performance. Harvard Business Review, Jan.-Feb. pp. 71-79.

Kaplan, R., Norton, D. (1996) Using the Balanced Scorecard as a Strategic Management System. Harvard Business Review, Jan.-Feb. pp. 75-85.

Kaplan, R., Atkinson, A. (1998) Advanced management accounting. Third edition, Prentice Hall, ISBN 0-13-080220-4. p. 376.

Kliem, R., Ludin, I. (1992) The people side of project management. 1994 reprint, Gower, ISBN 0-566-07363-3. pp. 12-15.

Leadbetter, A. (1996) Can we afford the bridge rebuild cost? Assessment and demolition of structures conf., Inst. Civ. Engrs., Sep 1996.

Leeming, M. (1993) The application of life cycle costing to bridges. Bridge Management 2, Thomas Telford. pp. 574–583.

Loudon, N. (1995) Structure management plans and whole life costing. Bridge Management Conference, June, London.

Markow, M. (1995) Highway management systems: state of the art. ASCE Journal of Infrastructure Systems, Sep. pp. 186–191.

Mishan, E. (1988a) Cost Benefit Analysis, Fourth edition, 1994 reprint, Routledge, ISBN 0-415-10922-1. Part VI.

Owen, K. (1995) Life cycle cost management: a client's view. Risk management in civil, mechanical and structural engineering conference, 22 Feb. pp. 143-161.

Parrott, N., Moyes, A. (1997) A Delphi Evaluation of the Environmental Impacts of Road Building. Environmental Policy and Practice, Vol. 7, No. 1. pp. 21-32.

Proffitt, J. (1994) Life cycle costs of aircraft systems. Colloquium on Life Cycle Costing and the Business Plan, Instn. Elec. Engrs., 1 Feb., Digest No. 1994/013.

Rigden, S., Burley, E., Tajalli S. (1995) Life cycle costing and the design of structures with particular reference to bridges. Proc. Instn Civ. Engrs Mun. Engr, Vol.109, pp.284-288.

Simon, O. (1996) The economic impact of transport infrastructure provision: a review of the evidence. Proc. Instn Civ. Engrs Transp., 1996, 117, Nov., pp. 241-247.

Singh, B. (1996) How significant is LCCA? Concrete International, Oct. pp. 59-62.

Sheath, D., Hall, M., Rowe, D. (Forthcoming) The effect of contract forms on construction project performance.

The Labour Party. (1997) In Trust for Tomorrow, Pre-election policy document.

Tilly, G. (1997) Principles of whole life costing. Safety of Bridges, Thomas Telford, pp. 138–144.

Treasury Taskforce: Private finance projects team. (1997) Partnerships for prosperity, Cl. 3.03.

Tsang, A. (1998) A strategic approach to managing maintenance performance. Journal of Quality in Maintenance Engineering, Vol. 4, No.2. pp. 87-94.

Vassie, P. (1998) Whole life costing of maintenance options. Bridge Management Conference, June, London.

Wallbank, J., Lickiss, D. (1990) Economic appraisal of durability options for reinforced concrete bridges. Transport and Road Research Laboratory report.

Willis, K., Garrod, G., Harvey, D. (1998) A review of cost-benefit analysis as applied to the evaluation of new road proposals in the UK. Transpn Research, Part D, Vol. 3, No.3. pp. 141-156.

Woodward, D. (1997) Life cycle costing – theory, information acquisition and application. Intl. Journal of Project Management, Vol. 15, No.6, pp. 335-344.

181 SECURING SUSTAINABLE BUILDING AND RESOURCE MANAGEMENT THROUGH PROCUREMENT OF SERVICEABILITY

D.P. Wyatt

University of Brighton, UK

Abstract

Building today may be seen as an inherited legacy, but one often found with an environmental life quality deficit, including a potential liability with its future loss of life quality and dismission. Nevertheless, many of the legacy's buildings have been built at a time where there were few environmental constraints, or concerns linking climatic changes, resource depletion or waste disposal with the built environment. But, it is the pursuit of that notion of sustainability, that may raise some doubts over the life viability or serviceability quality of this future's inheritance. Especially, when viewing the serviceability responses, in addressing those service loss arising from its wide mix of service life construction caught between what is 'acceptable' with 'what can be afforded'. Such challenges and uncertainty in life care practice, may also result in a disregard of that existing embodied energy laid up or even encouraging a premature loss of the durability attributes of those supply chains used. To address this lack of connectivity, it is suggested that serviceability is developed at several levels and widely adopted to optimise a building or portfolio's performance and service life quality. In doing so, linking its procurement with both its supply chains and their waste streams. Concluding, this paper suggests that if accepted as part of a whole life approach, serviceability could play a significant part in both the life care management of building portfolios and contribute to sustainable resource management practices based upon their service lives and their procurement.

Key Words. Life care, procurement, performance, service life, serviceability, sustainable cities, supply chain.

Durability of Building Materials and Components 8 (Volume Three). *Edited by M.A. Lacasse and D.J. Vanier*. Published in 1999 by NRC Research Press, Ottawa ON K1A 0R6, Canada. ISBN 0-660-17742-0

1 Sustainable building and resource management

Mounting evidence of disturbing, climate changes (including rising levels carbon dioxide emissions (Nunn 1998)), continuing migration away from rural communities, changing work practices and the very way modern cities work, have begun to challenge the way we live, and build. So it is prudent to ask, '"How will one respond to the challenge of developing sustainable built environment practices"? Further, what should one build to secure this and in what built environment?

One response to this question for the physical state of what has been built, is, a statement of intent? Perhaps the built environment focus should be, 'one of seeking and evolving ecologically based urban environments whilst at the same time, developing and building appropriate service life buildings' (i.e. sustainable life constructions). In so doing, securing an effective whole life building care and a resource management practice.

It could also be argued, that by far the greatest initial adverse built environment's impact on the environmental capital deficit account, has already taken place. In deed incurred by having used the materials and components of those supply chains drawn upon to lay down these buildings and their support infrastructures.

In fact, much of the built environment legacy has been constructed at a time where there were few or real environmental concerns. Indeed, it was only recently, that energy management standards themselves have assumed any real importance in building and are yet to fully impact upon those building stocks built, before the new standards were introduced.

So what course or courses of action, or price, has to be paid for and the procurement pathway to secure a sustainable city or their portfolio stocks of buildings? Especially, when turning to and reflecting upon those implied relationships in Figure 1. This diagram below intimates that the raison d'être for the supply chain movement, is to create a facility or space domain in order to serve a built environment need. The respective supply chain, in turn, is embodied, or trapped in the building formed and will remain in service until such time, as it is released from its service life into the built environment as a waste stream.

In this process of the inward, stationary and outward movement, negative environmental attributes are incurred, which may adversely impact upon climate, ecology, hydrological cycles and landscapes. But the positive attributes of the supply chains embodiment, or embodied energy remain so long as they remain in service.

In reviewing the service quality of the built environment, it is also evident that poorly managed replacement cycles are themselves likely to contribute to impact again on other unspoilt landscapes. Yet future redevelopments may well become shaped by planning authority environmental policies, economic considerations or a CO2 delimiter. On these basis alone, the big S relationship in Figure 1 is seen as highly relevant for procurement and asset management and its life care.

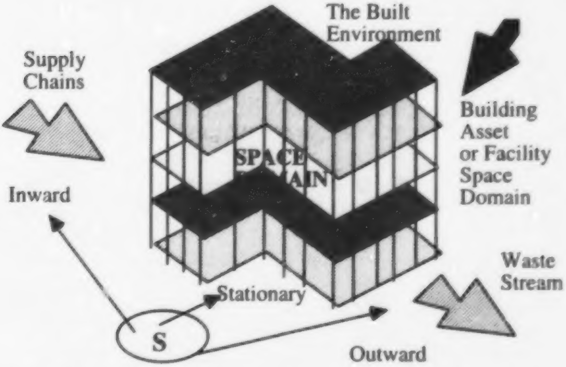


Fig. 1: The links of the Big S resource and asset management

2 The built environments assets management measures

In fact, the Big S embrace provides a way of appraising life care management decisions within the asset or building supply chain as well as the service loss with its potential waste stream. Nevertheless, there must also be recognition of the business world and its management of the building portfolio, including the threats faced.

To identify the threats to the portfolio, Table 1 has been included, to show the range and type and to also indicate an appraisal approach with a basis of measurement that could be used, to quantify their implications and make decisions.

Before exploring this Big S further, it should be also be noted that in establishing Table 1 it became clear, that as a matter of some urgency, that a common measurement framework needs to be developed. Likewise the measurement base must be capable of being used for both new and existing buildings and also universally accepted.

It is also believed, that a range of measurements appropriate to each business and environmental user, may have to be considered through out a building life with its material and component supply chains. Nevertheless, for both stakeholders and key holders, one might wish to see some common form of currency, or eco-point accounting and new evolving procurement approaches with liability framers.

The pursuit of environmental objectives are not in question, for they are on the table. Nor are they optional, for example, the CO2 reduction targets set at Kyoto have since been agreed by many governments. But the common framework needed is likely to also include a CO2 weighting. If so, it will probably bring both the resource and waste streams together within both the design for and life care of buildings. But this framework must also be able to address, both performance and reliability issues throughout the life care management and replacement cycle of buildings set within a whole life cost context and their serviceability.

Table 1: Impact and threats to a non sustainable building stock

Impact or threat	Appraisal approach	Measures
Planning Controls	sustainable policy /strategy	EIA-sustainable agenda requirements
Business Innovation	duty of care, customer focus, auditing, legal enactment's and directives & auditing	bench marking, audit conformance, changing ems policy procedures
Social	surveys questionnaires	opinion-responses
Economic Life Time	whole life cost management performance audit	life cycle costing actuarial tables. fitness in use
Material Component Supply Chains	Life cycle assessment to the project gate. Ecovert-durability-service life	Ecolabelling- greeness EE:CO2 audit reference service life
Legislation	performance or prescriptive requirement risk assessment	performance delimiters and penalties
Obsolescence	surveys and trend tracking and fashion	risk appraisal & POE
Quality Standards	product audit & service life quality planning	procurement-reliability & performance standards
Functional-Technical	EE.LCA.LCC performance & service life planning-auditing	serviceability
Dismission Dispersal	waste stream and recovery serviceability	landfill tax and spot market

To encourage development of this common framework, it is suggested much of relevance can be gleaned from around the world. For example, from research and development work in, embodied energy (Amato 1996), best practice initiatives with an ecological focus, (Huovila et al 1998) determination of the 'Eco effect' using a reference building and a life cycle costs methodology (KTH 1998) and finally, a computer based system centred around life cycle analysis (Lippiat 1998).

Focusing briefly on an older building's life care management, it should be kept in mind, that as the building ages, the problems arising from neglect, misuse, catastrophic events like fire, weak specifications, poor detailing and obsolescence may be found, that do not fit easily into this notion of common framework. Even if one could use a reference service life, (ISO 15686 1998) for an existing building, or reuse recovered materials, or components, other difficulties are also likely to surface. So it is necessary, to provide a number of pathways for upgrading or modernising old and worn out buildings, that may not be seen as entirely environmentally compatible.

But the need to balance the rate of change to the dismission state means that some form of space recovery , change of use or upgrading may have to be found which is practical enough to move on to a sustainable life time footing. Concluding, as the title of this paper implies, between the two material logistic movements of a building's life span, there is a need to secure a serviceable life quality of building, within any CO2 delimiter set, as long as it is practical to so. This life quality must also include life procurement and the intervention or replacement strategies end date.

3 Intervention in the serviceability domain

The physical quality and behaviour of buildings, whether attributed to space quality, acceptability of the configuration or because of some basis of physical fitness for purpose, inevitably changes during their standing life. Not only may service losses begin to build up, but they may in turn lead to other areas being put at risk. If this is left to continue, there will be a gradually a linking up with other service loss areas until, suddenly, a critical change in the fitness for purpose of the building, component population or systems in question occurs. Something of this state is now shown in Figure 2 below.

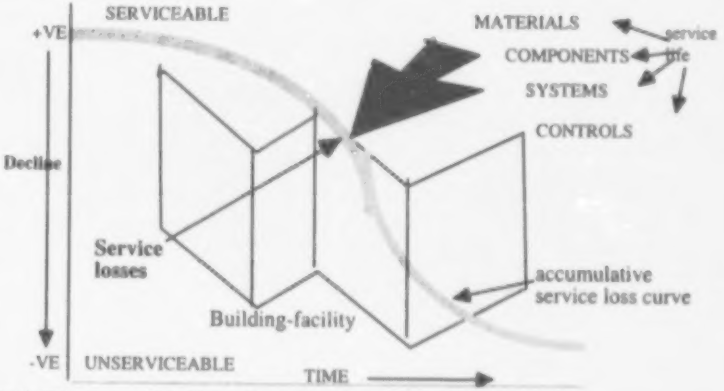


Fig.2: The unserviceable and serviceable relationship

As indicated, any service loss not contained, or if such a service loss corrective action is postponed, or no action is not taken until a critical point is reached, it will in fact, result in an accumulative curve of increasing loss of performance. At some point during this growing accumulation of service losses one will have seen a material, system, component or facility, or of course the building or building stock its self move from a serviceable to an unserviceable state.

Beyond a certain point, then, serviceability problems will begin to prove not only expensive to recover, but they may also may start to threaten the integrity of whole cities, an area or district of a town, down to a building's facility, or initially a system, element, or similar building components or surfaces. Eventually, if unchecked, this continual service loss accumulating, will lead to a poorer and poorer serviceability quality. That is, unless a substantial recovery operation is mounted and the necessary investment secured.

Inevitably there is a risk of a conflict of needs, to address, such maintenance or service losses, with the serviceability needs and repair budgets within also perhaps a wider funding need. So in some instances, this serviceability response is one of patch and make do and mend conflict, rather than replace.

Even though not ideal, the long life serviceability attributes of the building or area need not be seriously eroded. So the importance of the intervention timing and the notion of zones of critical intervention (with their varying degrees of tolerance), suggests one can accept a service loss in some areas. For example, a floor covering may wear unevenly in a canteen or corridor, or a surface of stonework may deteriorate over aeons of time, yet the wall remain serviceable, or an asphalt flat roof may be patched or have a capping sheet placed over it -but will now not leak!

Alas, in this process, one is continuously accepting an erosion of performance, especially of the original integrity and cleanliness. Nevertheless, one can argue that a significant amount of serviceability loss is open to remedial work, but, unlike the inference of maintenance, 'return to a former state,' there are no compelling reasons why one should do so. Nor why one should not, as a building or portfolio or city ages, accept certain levels of unserviceability. That is until now, for if sustainability considerations make the link between Figures 1 and 2 together with a CO2 index both the dismission state and life management will assume major significance.

But a caveat too. Degradation or a 'loss of service, is in effect the result of a dynamic process of which some is man made and some of a natural progression. (Wyatt 1999). So, there may be a call for a revaluation of asset and facility management practices, intervention timings (Johnson 1999) and the strategic role of serviceability in securing, a sense of sustainable building and life care management.

4 The serviceability business model

Serviceability, is in effect a way of reflecting or evaluating a design, life care, performance quality, and the impact of service losses, however caused. Serviceability applies equally, to any stage of a building, facility or its constituent parts in their service life cycle. in terms of this paper, serviceability however, is seen as a;

'critique or value judgement, state, process, a condition of the asset, or facility management standard practised, designed for including the specification or detailing quality of construction , or a course of action taken in use over a specified period in a given environment.' (Wyatt 1989)

The significance of this 'statement cum definition' may now be extended. Turning to Figure 3, one can suggest the serviceability state separates the positive attributes from the negative attributes of life care. This state can readily include all materials, components, systems and controls themselves within their own embodied energy detained in that building, facility or portfolio.

So the procurement serviceability goal might be said to be, 'to secure life care practices, economically (including resource management) and secure a flexibility, reliability and ease of servicing that matches the asset and facility needs, in changing conditions over time, yet seeking to reduce unnecessary loss of service life quality, nor putting at risk their service life crafted or environmentally engineered building or their embodied energy.'

Now, few should doubt that a focus for building serviceable quality, is anything but a step in the right direction for improving life care of building and environmental resource or sustainable management. At the same time, the importance of the customer culture as one adjust to 'green and sustainable building thinking (Anink et al 1996) should be increasingly kept in mind.'

But, the desire to have an effective building life care, is influenced by the wide range of building clients, tenants and building users that exist. As indeed are their degrees of sophistication and abilities to effectively respond to and secure life managed building stocks and sustainable practices.

Nevertheless, no serviceability initiatives will secure adequate sustainable building without the support of a whole life procedural framework that is also linked within and forms part of the business plan. Such business plans need to also support their building and facility portfolio replacement and life care management strategies and include a number of serviceability options. Above all, the whole needs to be properly under written with an adequate budget and life time funding.

Most buildings do have a service life fix, which permits then to continue as long as the building is wanted or expenditure is afforded But the very serviceability standard set seems itself to wobble, between, 'if it is acceptable don't fix it' or 'fix it if affordable' when push gives way to shove! But is this life care or serviceability management? Is it prudent life care management or even good stewardship for the handing on of our heritage? Do we also have an appropriate procurement delivery system in place let alone the information base for life management?

Whilst a little mischievous, it does appear in some situations, that irrespective of the quality of life care given or not given, the building or facility may not be liked, or suddenly becomes unwanted. But at the end of the day, building and facility serviceability quality is a reflection of business corporate cultures and their life care value systems. It may also become increasingly a reflection of their attitude to environmental responsibility and management practice and level or lack of understanding of the embodied energy laid down and its future implication or threat. So what relevance and context is there, for sustainable development in Vitruvius's statement, in figure 3 below?

There is a sound business case for gradually re-evaluating the whole life approach for all building stocks. That is at both the strategic and tactical levels of business planning. Indeed, by carrying out a life performance audit ,will help to face up to the issue of maintenance arrears, service loss, space quality, etc. In addition, a fuller audit should also be had and might include, the embodied energy and estimated waste stream flow rates or the risks and costs arising from various serviceability scenarios set against a notional carbon tax and rising landfill charges.

Indeed, this audit function could fit within that EQF business excellence model already developed, leaving businesses to bench mark and promote best practice initiatives for all development, life care and future service life management.

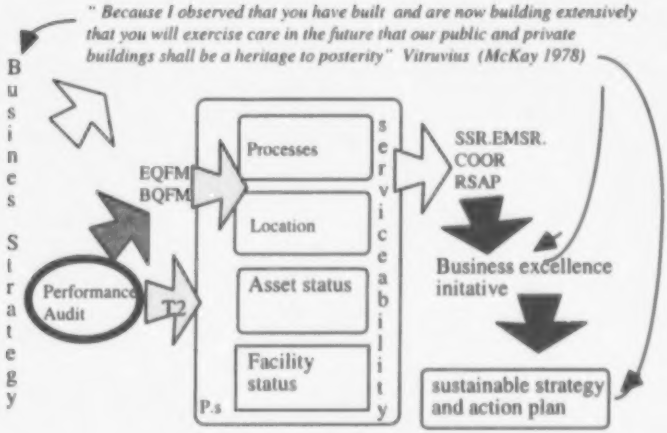

" Because I observed that you have built and are now building extensively that you will exercise care in the future that our public and private buildings shall be a heritage to posterity" Vitruvius (McKay 1978)
Business Strategy
EQFM
BQFM
Performance Audit
T2
Processes
Location
Asset status
Facility status
P.s
serviceability
SSR.EMSR.
COOR
RSAP
Business excellence initative
sustainable strategy and action plan

Fig.3: Developing a life care business action plan

5 Service life management

Generally, designing and managing many projects have tended to be geared to cost minimisation, whilst their life cycle assessment (Wyatt and Soronis 1998) or care, may not have become a significant consideration, until after hand over. This action, may conflict with those aspirations of sustainable development with those of the business needs of profitability in a fiercely competitive commercial world.

But, and it is a big but, managing and sustaining serviceable buildings and supporting infra-structure has to occur sometime. Indeed, *the longer the delay in moving to a service life management, the greater the environmental constraints will be found.* And it will cost some one some where, so what price for global warming?

On that basis, the serious threats likely to arise from waste management and CO2 delimiters suggest that the embodied energy risks in life care and dismission stages should perhaps now be more fully investigated. In doing so, also examining the durability attributes and serviceability short comings within the dismission audit. Also noting, that even obsolete buildings can be recovered with some imaginative restructuring of space and form! For once the embodied energy is laid down, ways can be found to extend the building life and sustain the facility and accept a wide change of use. But one may need to refine the project-procurement process to do so.

So, understanding serviceability management and its place in the cradle to grave cycle, is an important aspect of both sustainable cities and asset and facility management practice. Equally, it may also come to be seen, as sound business practice as ISO 9000 and ISO 14000 merge into one auditable management system.

6 A way forward for now

Whilst little published experience exists in service life practices especially concerning building upgrades, it only a question of time for some one to adopt ISO 15686. Perhaps in doing so, drawing upon established life cycle assessment methodologies that permit a comparative life quality of decision making to be made.

But it is even more evident that a proper modus vivendi is needed which will link the Big S embrace, as well as the financial, design and resource management disciplines own measures and performance criteria. In consequence, Table 2 is included in an attempt to set down some of the linkages issues that may be seen emerging with Table 1 with that goal of linking sustainability and serviceability.

In this review, it should also be kept in mind, that space and its management will play an increasingly significant part in the future and in the way existing buildings may be chopped about, cut up, extended, re-sculptured and changed in use. All this will fit within the serviceability appraisal and possibly meet a blend of durability and sustainable practice too!

Table 2: Linkages in serviceability, sustainability and resource management

Serviceability Appraisal	Performance Actions or Criteria	Sustainable and Resource Management Measures
Performance	Reliability	design agenda
Space	Building life span	Space audit quality-flexibility
Service Life	Material Component	service life planning
Accessibility	Building Systems	Renewable -Non Renewable
Frequency	Performance	Reusable Non Reusable
Recovery	Life Time	Time to Servicing-Failure or
Cleaning	Specification	Replacement
Reliability		Undockable and Redockable
Serviceable design	Reference Service Life	service life upgrade and
life quality costs		internal relocatability
Ecopoint life Weightings	Environmental Life	Whole Life Delimiters
incl. Embodied Energy:	and Service Life	Bldg Reconfiguration-Retained
CO2	Profiles	Flexibility
	Reliability	Life cost options
Futurescope	Life Care Review	Service Life Profile
service life profile	Space -	EE: CO2 Deficits
service life audit	Systems P & R TTF	Amelioration strategies
LCA		
Dismission Audit	Serviceability status	Recovery Plan
		Market> return to sender
Risk Assessment	Condition> Threat >	Cost and Time To Critical
Procurement method	Reliability Analysis	Event or Service Intervals
		Ecofile life cycle assessment

Moving on, asset and facilities management will find as service life planning experience grows and life care plans are provided, some aspects of serviceability will be easier to manage. Further more, flexible space, relocatable, undockable, recoverable, service life, design engineering and management are but a few terms that will become more daily, currency as the works and ideas of the CIB W60, CIB 80.TSL 140, CIB W94, CIB W86 and the ISO 15686 become part of the practice world, of service life and service life planning with future sustainable developments.

7 Conclusion

Understandably, what society has inherited has had to respond to some economic consideration, though little evidence of real life care costs arising from service loss or its recovery relationship have been identified here. But this dearth of information may not be the case in the foreseeable future. So it is suggested that both the service life, and its serviceability together with the embodied energy within the building's wastes and replacement cycle should be integrated into a whole life cost model.

Serviceability as both a value judgement and a discipline can embrace resource and procurement management. There is also an additional possibility for encouraging reuse and extending the life of existing materials, components and buildings on a time and conditioned related basis. That is by optimising upon the durability properties and service life remaining serviceable with or with out life care.

One consequence of this however, is the need to also understand the energy-CO2 relationship with a conditioned based service life state. Likewise, the place of life cycle assessment needs to seen more at an operational in use strategic level (Cole 1996). Here the understanding of the whole life of a material supply chain and its casting on and of a building may provide a service life pathway for further investigation in a that sustainable city context and procurement strategies-systems.

Mean while, the serviceability needs to become an integral part of performance operating standards set within a whole life context and in turn one needs to move to seeking sustainable procurement. In deed, serviceability seems to touch, link and reflect much of the asset and building life loss of service life quality. So, used for a critical review of life care of the building portfolio and its facility provisions, it will help raise the quality of decision making with those challenges faced in the built environment's post occupational stages and now that construct of sustainability.

8 References

Amato et al (1996) Embodied Energy. A Method of Assessment. New Steel Construction April /May Issue Steel Construction Institute 4pp

Anink D et al (1996) Handbook of Sustainable Building. James & James Publisher UK 175pp

Cole R (1996) Using Life Cycle Analysis as a basis for decision making in building design. CIB TG8 Warsaw Building & the environment in Central and Eastern Europe 99-110

Huovila P. Hakkinen. T Alto I (1998) Sustainable construction in Finland: Approach: and best practice CIB World Congress. Galve Symposium D 2161-2168

ISO 15686 (1998) Buildings Service Life Planning Part 1 General principle BSI UK 51pp

Johnson M and DP Wyatt (1999) Preparation and prioritization of maintenance programmes 8dbmc Vancouver 10pp

KTH (1998) The ecoeffect method and GBC 98 Focus Bulletin No 2. Royal Institute of Technology Galve Sweden

Lippiat B (1998) Building for environmental and economic sustainability (BEES) CIB World Congress Galve Symposium A. Vol. 1 779-787

Nunn JF (1998) Evolution of atmosphere Proceedings of the Geologists Association No 109 10

McKay A (1978) Vitruvius, Architect and Engineer: Buildings and Building Techniques in Augustan Rome. Bristol Classical Press 81pp

Wyatt D and Soronis G (1988) Life Cycle Assessment and the Design Agenda CIB W96 The Design Agenda Conference Brighton 11pp

Wyatt DP (1999) A Natural Progression: Neglect To Decay. 8dbmc Vancouver 10pp

PART FOURTEEN

LIFE CYCLE ANALYSIS AND SUSTAINABLE, DURABLE DESIGN

LIFE CYCLE ANALYSIS (LCA)

182 IMPACT OF ENVIRONMENTAL, HEALTH AND SAFETY ISSUES ON COATING USED FOR OFFSHORE FABRIC MAINTENANCE: A LCC ANALYSIS

A. Al-Hajj[1] and N. Thompson[2]

[1]The Robert Gordon University and [2]Salamis (Marine and Industrial) Limited, Aberdeen, UK

Abstract

Concern within society regarding both environmental & health and safety issues, has resulted in the introduction of new legislation in Britain. These regulations have forced the British paint industry to revise their formulations and develop a new generation of modern coating systems.

This paper describes the cost model developed for calculating the total life cycle cost for offshore fabric maintenance painting. The model compares the difference of the life cycle cost between fabric maintenance painting using modern coating technology, with that of traditional coating technology, on a offshore platform underdeck and jacket.

The results of the study show that the modern coating technology is not only less harmful to both the natural environment and applicator, but has a significant lower life cycle cost.

Keywords: environment, fabric maintenance, legislation , life cycle costing model, offshore coating systems

1 Introduction

There has been increasing pressure in recent years on the UK paint industry to revise the formulations of coating systems. This has been caused by a growing realisation within society of the need to protect both the environment, and the health and safety of workers. In response to international obligations, the UK government has introduced new legislation in the form of the Environmental Protection Act 1990 (EPA). The emission of Volatile Organic Compounds (VOCs) has had a significant impact on industrial coating technology development because the majority of solvents traditionally used in paints are classified as VOCs. VOCs can be defined as: "*.. a large family of carbon-*

Durability of Building Materials and Components 8 (Volume Three). *Edited by M.A. Lacasse and D.J. Vanier*. Published in 1999 by NRC Research Press, Ottawa ON K1A 0R6, Canada. ISBN 0-660-17742-0

containing compounds which are emitted or evaporated into the atmosphere and can take part in photochemical reactions in the air" (DOE).
Further impetus towards changes in coating formulations is given by the Control of Substances Hazardous to Health Regulations (COSHH), which requires an employer to prevent, where reasonably practicable, exposure of employees to harmful substances.

These environmental and health and safety issues have forced the coatings industry to develop a new generation of coating systems. The questions which the research sought to answer in this paper was whether these new coating systems would increase the cost for fabric maintenance painting (FMP) of platforms, or provide a more cost effective solution. To make such an assessment a comparison was made between traditional coating technology used in the industry and modern coating technology, developed as a result of the new regulations. This comparison could not be made on capital costs alone because this makes no allowance for future running costs. Only by calculating total life cycle costs of both new and traditional coating systems would the cost implications to fabric maintenance painting (FMP) become evident. Unfortunately, since the industry had traditionally relied on capital costs, no life cycle costing (LCC) model existed for comparing the coating systems.

The introduction of legislation such as the Control Of Substances Hazardous to Health (COSHH) Regulations has brought health and safety issues to the forefront of the industry. These regulations came into force on the 1st October 1989 aiming to protect people against risks to their health, either immediate or delayed, from substances hazardous to health arising from a work activity. Long (1991) believed that the industry has been reluctant to change despite the fact that some long-term studies of painters have highlighted a number of possible health problems amongst which is a greater than normal risk of cancer.

2 The development of new protecive coating technology

The most important force behind the development of new coating technology within the industry is the increasing legislative control over the environment, and health and safety of the work-force (Nielson & Hansen, 1994). Howe & Wach, (1991) saw other reasons for this rapid development; new substrates, world-wide competition and the European Single Market have all played their part.

To reduce VOCs in compliance with environmental regulations, the surface coating industry is re-examining the production, application, and disposal of paints. Production facilities and applicators of coatings are introducing pollution prevention. The future development of protective coatings will, therefore, concentrate on trying to reduce the use of solvents in the paint formulations. The main alternatives to the industry are the following:

- Water-based coatings
- High solids coatings
- Powder coatings
- Organic solvent-free liquid coatings

- Radiation cured coatings

Not all of the alternatives will be practicable for each sector of the coatings industry. With regard to fabric maintenance protection in the offshore industry, Nielson & Hansen (1994) believes that water-borne and high solids/solvent free coatings are the most likely alternatives.

The following section of this paper will discuss the cost implications for fabric maintenance and describes the cost model developed in order to compare the life cycle cost for fabric maintenance painting using modern coating technology, with that of traditional coating technology, on a platform under-deck and jacket.

3 Model development methodology

To develop a Life Cycle Costing model to paint techniques all the pertinent costs associated with FMP were identified with the collaborator (SALAMIS Ltd). These costs were divided into two distinct phases, as shown in the life cycle costing Figure 1 for fabric maintenance painting:

- **Capital Expenditure (CAPEX)** - The cost of applying the coating system in the construction yard and repair work required during the hook-up phase.
- **Operational Expenditure (OPEX)** - Cost of repairing the coating system and eventual replacement when it reaches a suitable level of breakdown.

Having identified all pertinent costs associated with the use of industrial coatings for FMP the next stage would be to determine what the actual costs were. With the absence of any sufficient or appropriate historical data, estimated data from various organisations within the industry were used (see Figure 2).

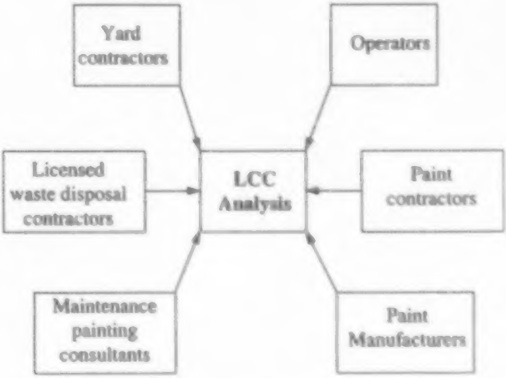
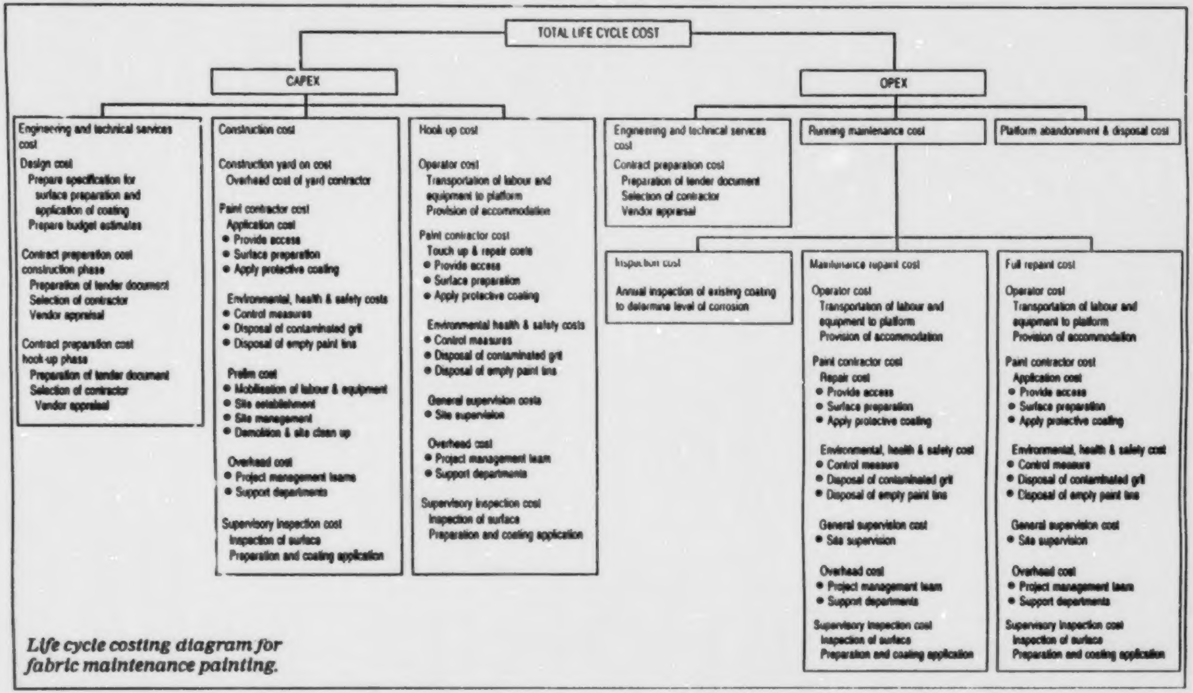


Fig. 2: Data sources for LCC analysis


TOTAL LIFE CYCLE COST
CAPEX
OPEX
Engineering and technical services cost
Design cost
Prepare specification for surface preparation and application of coating
Prepare budget estimates
Contract preparation cost construction phase
Preparation of tender document
Selection of contractor
Vendor appraisal
Contract preparation cost hook-up phase
Preparation of tender document
Selection of contractor
Vendor appraisal
Construction cost
Construction yard on cost
Overhead cost of yard contractor
Paint contractor cost
Application cost
● Provide access
● Surface preparation
● Apply protective coating
Environmental, health & safety costs
● Control measures
● Disposal of contaminated grit
● Disposal of empty paint tins
Prelim cost
● Mobilisation of labour & equipment
● Site establishment
● Site management
● Demolition & site clean up
Overhead cost
● Project management teams
● Support departments
Supervisory inspection cost
Inspection of surface
Preparation and coating application
Hook up cost
Operator cost
Transportation of labour and equipment to platform
Provision of accommodation
Paint contractor cost
Touch up & repair costs
● Provide access
● Surface preparation
● Apply protective coating
Environmental health & safety costs
● Control measures
● Disposal of contaminated grit
● Disposal of empty paint tins
General supervision costs
● Site supervision
Overhead cost
● Project management team
● Support departments
Supervisory inspection cost
Inspection of surface
Preparation and coating application
Engineering and technical services cost
Contract preparation cost
Preparation of tender document
Selection of contractor
Vendor appraisal
Running maintenance cost
Platform abandonment & disposal cost
Inspection cost
Annual inspection of existing coating to determine level of corrosion
Maintenance repaint cost
Operator cost
Transportation of labour and equipment to platform
Provision of accommodation
Paint contractor cost
Repair cost
● Provide access
● Surface preparation
● Apply protective coating
Environmental, health & safety cost
● Control measure
● Disposal of contaminated grit
● Disposal of empty paint tins
General supervision cost
● Site supervision
Overhead cost
● Project management team
● Support departments
Supervisory inspection cost
Inspection of surface
Preparation and coating application
Full repaint cost
Operator cost
Transportation of labour and equipment to platform
Provision of accommodation
Paint contractor cost
Application cost
● Provide access
● Surface preparation
● Apply protective coating
Environmental, health & safety cost
● Control measure
● Disposal of contaminated grit
● Disposal of empty paint tins
General supervision cost
● Site supervision
Overhead cost
● Project management team
● Support departments
Supervisory inspection cost
Inspection of surface
Preparation and coating application

Life cycle costing diagram for fabric maintenance painting.

Fig. 1: Life cycle costing for fabric maintenance painting

The research was restricted to considering the jacket and under-deck. This area was chosen because it is a large work-scope which is easily definable; it requires only two different specifications, one for the under-deck and Atmospheric Zone, and one for the Splash Zone; and that this area is subject to less mechanical damage than the topsides of the platform.

The basis of comparison was formed by developing generic specifications for the alternative coating systems.

The specifications were based on the following:

1. Under-deck and Atmospheric Zone of Jacket

Traditional System	-	Four coat epoxy system (polyurethane topcoat)
Modern System	-	One coat high build/high solids glass flake epoxy.

2. Splash Zone of Jacket

The individual life cycles of the different coating systems were determined by paint manufacturers and industry experts, who were asked to predict, based on a given criteria, in which year, the coating system would have to be repaired and replaced. Both the manufacturers and industry experts believed that the modern coating system would have the longest life cycle.

The methodology for developing the LCC model incorporated the following steps:

- Outline model developed from pertinent costs
- The timing of the different FMP operations, during the platform's life were identified for each alternative coating system.
- The current cost of the FMP operations for each coating system were calculated and inserted into the model at the relevant year.

The costs of the different coating systems were compared by calculating their Net Present Value (NPV), and ranked in order of preference.

Since FMP is basically an expense item, which has no salvage or depreciation considerations, few calculations were required to compare the cost of the traditional and modern coating systems. The difficulty, however, was determining which discount rate and platform life to use in the model since both can have a significant impact on the ranking of the coating systems. This problem was overcome by testing the sensitivity of the LCC model results to changes in these factors. Samples of the results from the LCC model can be seen in Figures 3 and 4 below.

It is clear from these results that the modern coating systems are significantly less expensive (i.e. have a lower life cycle cost) on the under-deck and atmospheric zone. Further sensitivity analysis indicated that this ranking was independent of both the discount rate used and platform life. The results for the platform were less conclusive, with the modern coating systems only having the lower life cycle cost once the platform's life exceeded 10 years, irrespective of the discount rate used. But the life cycle cost of the splash zone is relatively small in comparison to the under-deck and atmospheric zone. Therefore when the two areas were considered together the results indicated that the modern coating systems had a lower life cycle cost in comparison with the traditional systems. This can mainly be attributed to the lower application costs and greater life cycles of the modern coating systems.

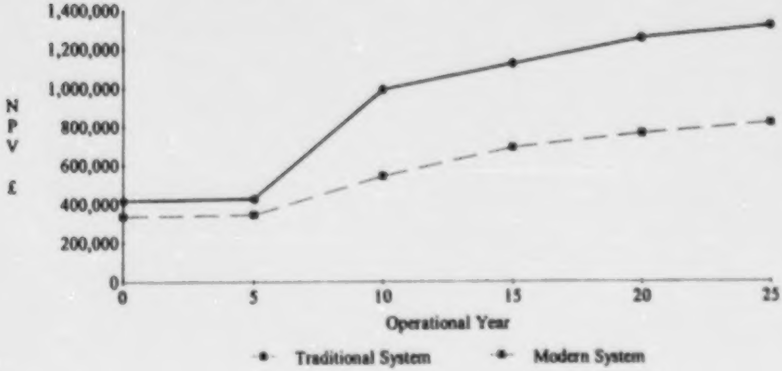


Fig. 3: LCC comparison of coating systems for underdeck and atmospheric zone, over different platform lives (net discount rate 10%)

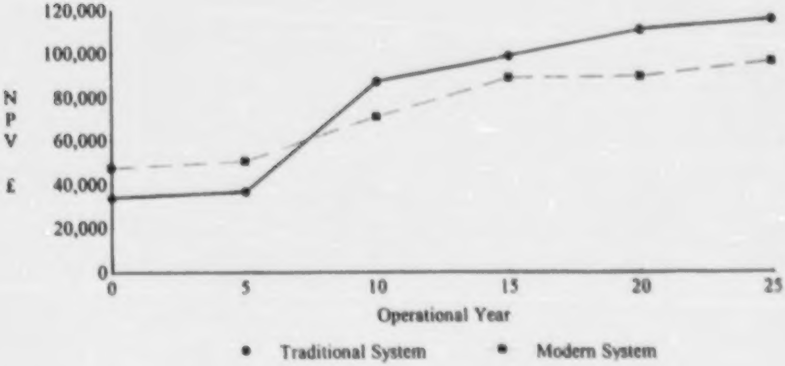


Fig. 4: LCC comparison of coating systems for slash zone, over different platform lives (net discount rate 10%)

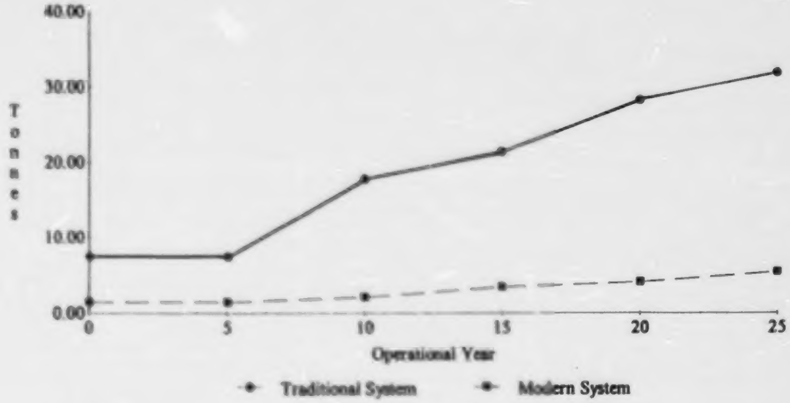


Fig. 5: Comparison of weight (tonnes) of VOGs released from fabric maintenace painting work, over different platform lives – underdeck and atmospheric zone

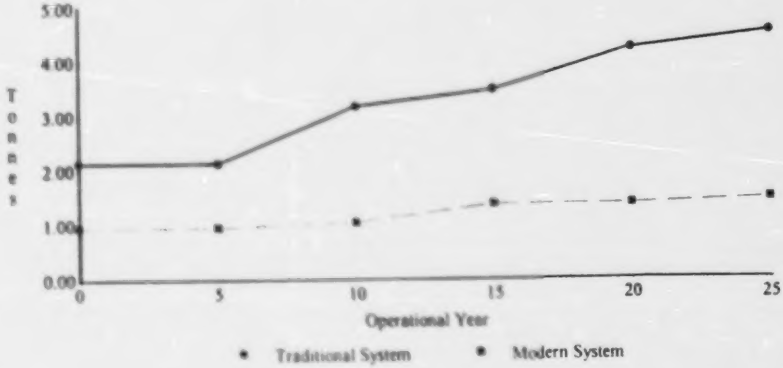


Fig. 6: Comparison of weight (tonnes) of VOGs released from fabric maintenance painting work, over different platform lives – splash zone

The environmental impact of the alternative coating systems over the life of the platform was also considered. Using product data information from a paint manufacturer, the tonnage of VOC released by the coating systems was calculated for different platform lives (see Figures 5 and 6). This analysis demonstrates how VOC emissions are substantially reduced when traditional coating systems are substituted for modern, high solids based coatings.

Although similar results may not be found for all FMP, this research has shown that it is possible not only to comply with the new environmental, and health and safety legislation, but to also reduce the life cycle cost of such work.

4 Conclusions

1. Insufficient historical data can be found in operators and contractors organisations for the LCC analysis. Thus, the LCC analysis had to rely on estimated data from a number of different organisations.
2. Paint manufacturers and industry experts both believed that the modern coating systems would have a longer life cycle than the traditional coating systems.
3. The modern coating systems used on the Under-deck and Atmospheric Zone was found to have considerably lower life cycle costs in both CAPEX and OPEX phases in comparison with traditional system. Furthermore, these results were independent of either operational life of the platform or the net discount rate used. In addition, although the results were less conclusive for the Slash Zone this area is relatively significant.
4. The modern coating systems released considerably less VOC into the atmosphere over the life cycle of the platform than the traditional systems. A further benefit found with the modern systems was a reduced risk to the health and safety of the applicator.
5. The new legislation has lead to manufacturers developing a new generation of coating systems which are not only less harmful to the environment and applicator, but also reduce the life cycle cost for FMP of offshore platforms.

5 References

Brevoort, G.H. (1993), and Roebuck, A.H., “A Review and Update of ‘The Pint and Coatings Cost and Selection Guide’”, Materials Performance, Vol. 34(4), pp31-45.

Dale, S.J. (1993), "Introduction to Life Cycle Costing". In Life-Cycle Costing for Construction, edited by Bull, J. Black Academic and Professional. Chapman & Hall, London.

Department of the Environment and the Welsh Office, “Integrated Pollution Control: A Practical Guide”, HMSO, 1994.

Department of the Environment, The Scottish Office, The Welsh Office, “PG6/23(92)- Secretary of State’s Guidance- Coating of metal and plastic”, Environmental Protection Act 1990, Part I, HMSO, 1992.

Ferry and Flanagan, (1991) “Life Cycle Costing- a Radical Approach”. CIRIA Report 122. London.

Howe, M., and Wach, M. (1991), European State of the Art in Industrial Liquid Coatings", Metal Fishing, Vol. 89, Part II, November, pp15-19.

Long, N.J.T. (1991), "Substitution of Hazardous Substances In The Finishing Industries", Finishing, Vol. 15, Part 1, January, pp33-34.

Marlowe, I. (1989), "Solvent Emissions From Paint Usage In The UK and Regulatory Control", Warren Spring Laboratory, Department of Trade and Industry.

Nielson, P.K. & Hansen, J.H. (1994), "Ecology and Economy in the Development and Use of Heavy-Duty Protective Coatings for Steel", 1st Middle East Conference on "Technical Developments In Coatings: Their Application And Uses" Paint Research Association, Dubai, 30 January – 1 February.

Owen, K. (1995), "Life Cycle Management- A Client's View ", Paper presented to the Health and Safety Executive's Risk Management in Civil, Mechanical and Structural Engineering Conference, ICE, London.

Randall, P.M. (1992), "Pollution Prevention Methods in the Surface Coating Industry" Journal of Hazardous Materials, Vol. 29, Part 2, January, pp275-295.

Warren, J.K., and Weitz, K.A. (1994), "Development of an Integrated Life Cycle Cost Assessment Model", Proceedings of the 1994 IEEE International Symposium on Electronics and the Environment", San Francisco, USA, pp155-163.

Willemse, F.R.J. (1991), "VOC Emission Reduction Through Coating Process Adaptations" in VOC-Policy of The European Paint Industry", First International Congress on Volatile Organic Compounds, Maastricht, Netherlands, March.

Zollner, W. (1991), "Introduction", in VOC-Policy of The European Paint Industry", First International Congress on Volatile Organic Compounds, Maastricht, Netherlands, March.

Zorll, U. & Jolly, M. (1991), Progress in Emission-Free Paint Technology", in "VOC-Policy of The European Paint Industry", First International Congress on Volatile Organic Compounds, Maastricht, Netherlands, March.

183 RELIABILITY AND WHOLE LIFE PERFORMANCE: INTEGRATING THE SUPPLY CHAIN

E.V. Bartlett and M. Clift

Building Research Establishment, London, UK

Abstract

This paper will discuss how research into building component service life and other whole life performance issues has led to the use of reliability engineering techniques. The UK construction industry has been looking at adopting a framework that allows the supply chain to consider service life, whole life cost and building component performance and environmental data during procurement and throughout the building's life. Integrated Logistics Support (ILS) is one possible framework developed for defence procurement that also includes these reliability techniques, and also allows whole life performance and cost issues to be integral. The paper will feature some of these techniques including Reliability Centred Maintenance and Failure Modes, Effects and Criticality Analysis (FMECA). The paper will also summarise recent research carried out in the UK that has examined the application of ILS to construction, and proposes an adapted framework that could allow the further development of ILS into a working model in construction (ILSC).

Keywords: Failure Mode Effects and Criticality Analysis, Integrated Logistics Support, maintenance, reliability, service life, supply chain, standards, whole life cost & performance

1 Introduction

Research into building services component service life and other whole life performance issues has led to the use of reliability engineering techniques. This adoption of cross-industry global techniques has created a shift in the way we look at buildings. We are encouraged to see buildings as products. There is a paradox here as buildings are seldom identical. The use of 'product' technology and

Durability of Building Materials and Components 8 (Volume Three). *Edited by M.A. Lacasse and D.J. Vanier*. Published in 1999 by NRC Research Press, Ottawa ON K1A 0R6, Canada. ISBN 0-660-17742-0

procurement methods however can certainly be applied in order to meet cost reduction metrics being sought. Clients are also starting to demand demonstrated real value and performance together with benchmarks. For this we require some level of common framework. The construction industry has been looking at adopting a framework that allows the supply chain to consider service life, whole life cost and building component performance data during procurement and throughout the building's life.

There has been much work in this area and the best method for handling of performance and costs-in-use data has been debated strongly in recent years. Research carried out by BRE into this area under the UK LINK Construction Maintenance and Refurbishment programme with strong industry support came to the conclusion that the key to its success, was the implementation of 'Building Data Spine' or 'BDS' (Clift and Butler 1995). Huge amounts of data are required to model performance throughout the whole life of a building and an extremely robust and tested model is required. Integrated Logistics Support (ILS) is one possible model that provides a framework that could incorporate this level of sophisticated data. ILS developed for defence procurement with reliability techniques at its core, allows whole life performance and cost issues to be integral. This approach would also complement the current movement in service life planning of buildings in relation to British Standards (BSI 1997) and International Standard ISO 15686.

2 What is ILS?

Integrated logistical support (ILS) mechanisms have been adopted within defence applications as a means of bringing together and managing the processes associated with the important resources involved in carrying out a project from inception to disposal. Recent research carried out by BRE for the UK government indicated ILS as being one example of successful whole life costing strategies in defence industries world-wide (Clift & Bourke 1999). In the US navy ILS was adopted to respond to the shrinking budget and the maintenance of complex ships, which must be retained in a state of readiness at all times. The planned life expectancy of ships has gone up from 20 to 40 years. The US navy has responded by developing maintenance programmes such as Planned Maintenance System (PMS) and Current Ship's Maintenance Project (CSMP) to optimise readiness, modernisation and planned replacements of obsolete equipment. Associated initiatives include Computer aided acquisition and logistical support (CALS) to integrate and use automated technical information for weapon system design, manufacture and support. The concepts underlying all these military procurement initiatives can be summed up as "build a little, test a little, learn a lot" (Clift & Bourke 1999). This can be contrasted with the construction industry – which has rarely developed designs from prototypes into standard, tried and tested solutions.

Within the UK, both reliability and maintainability assessment procedures have been adopted as Defence Standards, following on from work within NATO on their standards (STANAGs). Exploration of the need for guidance in setting reliability requirements for military equipment has led to advances in this area. Decision support programmes have been developed for modelling development costs (CORD), in-service costs (COUP) and whole life reliability models (DOCTOR: Wheatcroft 1985) which describes a suite of three reliability cost models for armoured fighting vehicles, together with the results of example applications

While the guidance is targeted towards equipment and moving plant, many of the principles described are transferable to construction. The military models and process maps were developed in respect of plant or equipment within a military context, but there is scope for technology transfer to construction processes and decision-making. These techniques may also foster the partnering and supply chain management approach, which the industry is encouraging.

ILS in its current format has four core activities within the framework that are applied throughout a product's whole life ('cradle to grave'):

1. Establishment of supply chain support status (develop, deliver, maintain, or terminate)
2. ILS support analysis - combines component reliability and failure analysis with the provision of maintenance requirements (e.g. Failure modes effect and criticality analysis, Reliability Centred maintenance)
3. Whole-life costing analysis
4. Other Integrated supply support procedures relevant to administration and human issues (e.g. documentation, ordering, invoicing, handling, skill requirements, training, testing etc.)

ILS also requires a plan, or an 'integrated logistics support plan' (UK MOD 1996), which is developed at design stage and remains in place throughout the life of the product. This optimises the reliability and maintainability (R&M) of the product in conjunction with the 'engineering support' or maintaining organisation. The plan addresses all lines and depths of maintenance as a coherent whole, which takes account of factors such as:

- The preventive maintenance requirements of the equipment in all environments in which it may be used or stored;
- The probable pattern of corrective maintenance operations;
- The maintenance opportunities arising in normal operations in order to schedule preventive maintenance into non-operational periods whenever possible.
- The spares and materials required supporting the predicted maintenance requirements;
- The maintenance logistic system;
- The test equipment and tools required for handling, maintenance and repair; sub-dividing these into special items, which will be provided by the equipment manufacturer, and the common tools and test equipment which will be provided by the maintenance organisation;
- The maintenance and repair information which will be needed by the maintenance organisation and the required format;
- The maintenance skills of personnel which will be needed by the maintenance organisation and what training will be required.

These reliability techniques and maintenance strategies that are part of ILS may be summarised as follows:

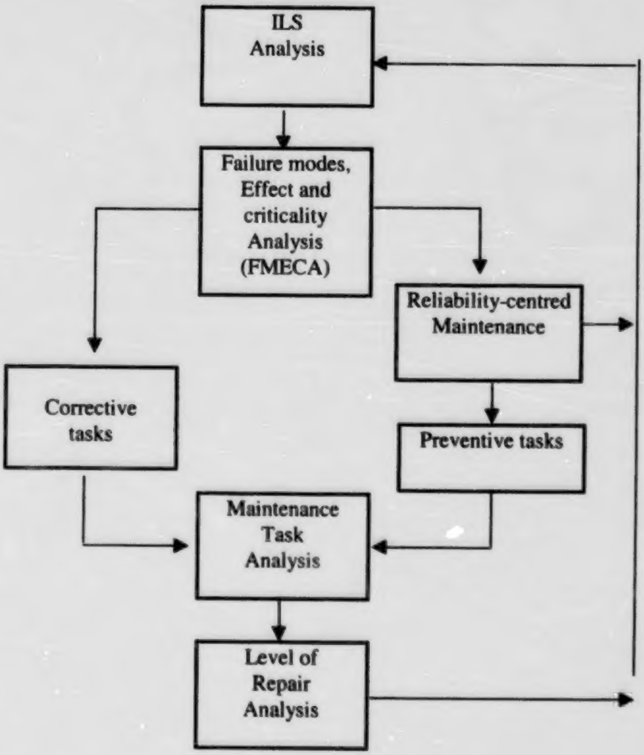

ILS Analysis
Failure modes, Effect and criticality Analysis (FMECA)
Reliability-centred Maintenance
Corrective tasks
Preventive tasks
Maintenance Task Analysis
Level of Repair Analysis

Fig. 1: Integrated logistics support analysis (UK MoD 1996)

As stated previously ILS has reliability engineering techniques at its core. The benefits of reliability engineering in construction have been demonstrated in relation to the assessment of building services component service life (Bartlett & Simpson 1998). Reliability Centred Maintenance (RCM) detailed above is a disciplined logic, or methodology, which is used to identify and implement preventive maintenance, tasks in order that the equipment attains its inherent reliability at minimum cost (UK MoD 1996). It is commonly used in the asset management of complex buildings involving large amounts of services components. RCM requires the identification of significant items; classified on the consequences of their failure; will failure affect safety, or have a significant impact on operations or economics. RCM demands the identification of the engineering causes for each functional failure, which may be accomplished by an

FMECA. Each engineering failure mode, for significant items, is to be analysed to determine if a technically feasible and effective maintenance task can be scheduled to safeguard the function of the item. If no task can be scheduled, then the equipment should be re-designed.

3 Recent related research & development

3.1 BRE research

A new approach to the assessment of the performance and costs-in-use of buildings was promoted by a BRE report (Clift & Butler 1995) which highlighted the need for a Building Data Spine as discussed in the introduction. Following on from this research work was carried out in the UK under the Partners in Technology (PiT) programme. This project team involved a major UK commercial organisation, an ILS software company, University of Reading, and BRE (University of Reading 1998). The aim of the project was to develop Integrated Logistic Support for Construction (ILSC) procurement, to achieve real cost reduction & improve operational performance (add value to client's business). This project introduced some of the key aspects of 'supportability' in the construction industry context (Fairey & Garnett 1998). The objectives were to:

- Identify and define the strategy of Integrated Logistic Support for Construction (ILSC).
- Determine how the methodology of ILSC can be used to reduce risk, improve the procurement process and optimise whole life costs.
- Determine how ILSC can achieve designs influenced by whole life cost, buildability, health and safety, operating and maintenance planning.
- Define standards for the use of ILSC within the construction industry.
- Define, develop and validate software, based upon a commercially available database customised to support ILSC.

Cultural changes were also addressed in order to ensure ILSC could add real value to construction, minimising client risk and ensuring efficient design on a whole life basis and thus fitness for purpose. This has yet to proven on a large scale and further development is needed to encourage client adoption of the approach. This is partly due to the fact that additional work is required to make ILS building specific and not an adaptation of a framework and software used in defence procurement in general. The project looked to use existing construction principles and existing software rather than develop expensive bespoke systems (Fairey & Garnett 1998). Successful case study applications of ILSC to lifts and package handling facilities in airports were carried out as part of the study.

In addition to this research, BRE carried out a project entitled 'Computerised Exchange of Information in Construction Industry' (Wix & Bloomfield 1995) which looked at CALS (Continuous Acquisition and Life Cycle Support) and its relevance to the UK construction industry. The report prepared for UK DETR found that further efforts should be made to establish 'de facto' standards for life cycle data exchange and sharing. The CALS approach is essential in providing the typical IT backup for ILS and is concentrated on the software provision. It does not however, provide a readily adaptable solution that is construction based. This possibly explains the lack of take-up of the approach at present. Further research is certainly needed in this area.

3.2 Other relevant research

Research at The Bartlett College (Young et al 1996) compared refurbishment in shipping and construction and identified substantial similarities and a number of transferable tools and techniques of benefit to both industrial sectors. This study did not specifically focus on whole life costs but emphasised the possibility of transferring ILS from defence to the construction sector. The University of Dundee (El-Haram et al 1998) has recently looked at the application of ILS to the development of cost-effective maintenance strategies for existing housing building stock. The project was funded under the UK EPSRC research program. The aim of the project was to determine the potential for applying ILS to the design of optimum support strategies, which would minimise the cost of maintaining existing building stock. This project came up with some interesting conclusions stating that there is considerable potential for the application of ILS to existing building stock. It was claimed that if the results of the study were replicated across all the UK publicly owned residential property, there would be a national annual saving of £250m or 18.5% (El-Haram et al 1998).

The developing series of standards on service life planning (ISO 15686) mentioned earlier includes parts on general principles, data requirements, maintenance and life cycle costing, and is also relevant in the context of ILSC. The application of this guidance could usefully take place with an ILSC framework.

4 ILSC – A proposed model & future research needs

It is noticeable that research carried out so far has been related to particular building types with ILSC being successfully applied to a number of M&E components and social housing. There is potential to adapt the framework for other building types and components. Using the UK Ministry of Defence (UK MoD 1994) framework as a base, a model is proposed in figure 2. There is scope for further research and robust testing of the model with it forming the basis of an ILSC toolkit that could be used throughout a building whole life cycle.

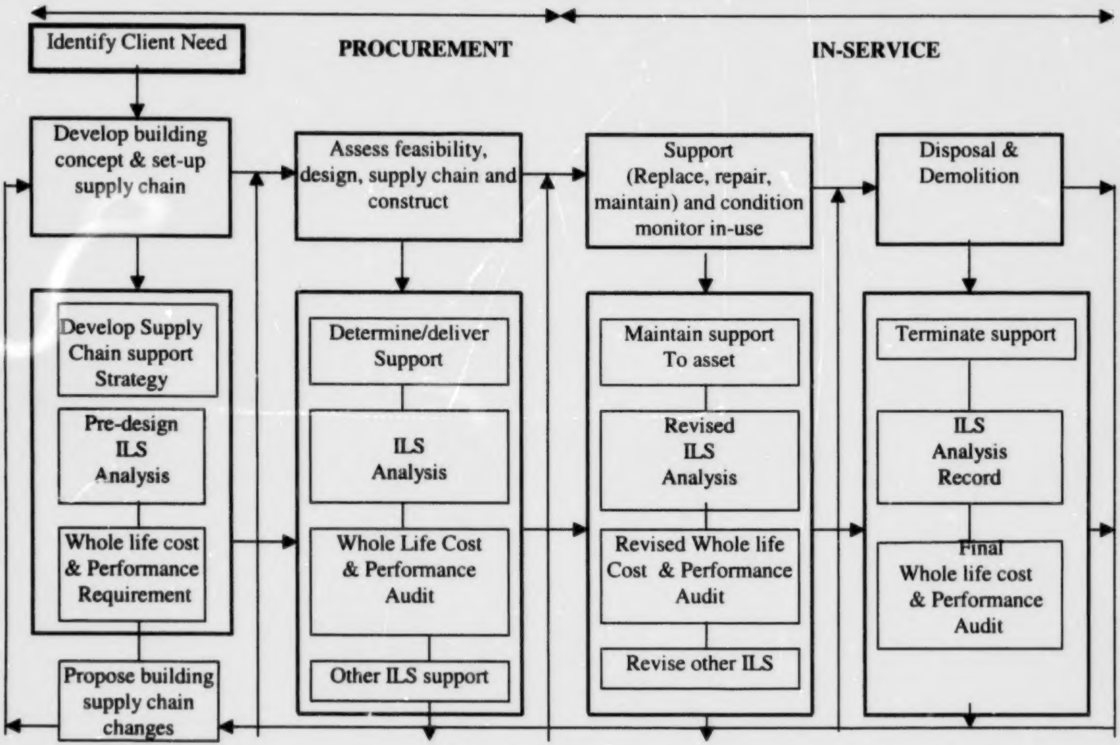

PROCUREMENT
IN-SERVICE
Identify Client Need
Develop building concept & set-up supply chain
Develop Supply Chain support Strategy
Pre-design ILS Analysis
Whole life cost & Performance Requirement
Propose building supply chain changes
Assess feasibility, design, supply chain and construct
Determine/deliver Support
ILS Analysis
Whole Life Cost & Performance Audit
Other ILS support
Support (Replace, repair, maintain) and condition monitor in-use
Maintain support To asset
Revised ILS Analysis
Revised Whole life Cost & Performance Audit
Revise other ILS
Disposal & Demolition
Terminate support
ILS Analysis Record
Final Whole life cost & Performance Audit

Fig. 2: Integrated Logistics Support Framework for Construction (adapted from UK MoD 1994)

5 Conclusion

ILSC is a framework that can integrate whole life cost data and performance data in one model. The framework and the process as a whole appear to fit in with international developments in service life planning. It is apparent however, that much of the work in ILS has been focused on the Information Technology implications of the framework. Questions need to be answered in future research in relation to the level of sophistication of buildings compared to defence products. Mapping of the similarities and differences of buildings compared to defence products is required. The level of IT use in ILSC will either force the change or make it too complex. Benefits of applying ILSC to certain building types have been demonstrated. The key to further development and successful use will depend on greater cross transfer of the technology to other building types over different stages of the building life cycle.

6 References

Bartlett, E. & Simpson, S. (1998) *"Durability and Reliability, Alternative Approaches to Assessment of Component Performance Over time"*, CIB World Building Congress, 'Symposium A', Sweden, June 8-12 1998

BSI (1997) *BS HB 10141 - Buildings - Service Life Planning, Part 1: General principles*, British Standards Institute, London, 1997

Clift, M.R. & Bourke, K (1999) *Study On Whole Life Costing*, Building Research Establishment Client Report for DETR, Number CR 366

Clift, M.R. & Butler, (1995) A.,, *The Performance And Costs-In-Use Of Buildings: A New Approach*, Building Research Establishment (BRE) Report,

El-Haram,M., Horner, R.M.W. & Munn,A.K. (1998) *Application Of ILS To The Development Of Cost Effective Maintenance Strategies For Existing Building Stock*, University of Dundee Construction Management Research Unit, 1998

Fairey, V. & Garnett, N. (1998) *How can construction benefit from the introduction of a supportability strategy*, Reading University and Dytechna Ltd.

Reading University (1998), *Cost of ownership through integrated logistics support for construction*, Advanced Construction Technology – Department of Construction Management and Engineering, Report - Jan 1998

UK Ministry of Defence (1996), *Integrated Logistic Support Part: 0 Application of integrated logistic support (ILS)* Defence Standard - 00-60 Issue: 1 Dated: 10-May-96

UK Ministry of Defence (1994), *Integrated Logistics Support – As A Basis For The Procurement Of Defence Equipment*, Section 51: Consultancy and Advisory Services guidance paper 062

Wheatcroft, P.A.C. (1985) *DOCTOR - Whole Life Reliability Cost Model* Int.J.Quality Reliability Mgmt, 1985, vol.2, no.1, pp4-17

Wix, J. & Bloomfield, D.P. (1995*), THE Relevance of the Cals Concept For Building Construction*, Building Research Establishment (BRE) Client Report prepared for Construction Directorate

Young, B.A., Torrence, V.B., & Egbu, C.O. (1996*) Managing Refurbishment Works In The Construction And Shipping Industries*, The Bartlett, UCL

184 BUILDING DURABLE AND SUSTAINABLE THE DUTCH WAY AND THE CONSEQUENCES FOR THE HEALTHY INDOOR CLIMATE

M. Ham and A. Van Bronswijk

Eindhoven University of Technology, Eindhoven, The Netherlands

Abstract

In the Netherlands durable and sustainable building is a hot issue. Ever since it has been recognized that neglecting pollution is very costly in the long term and that it makes sense to reduce the use of fossil energy since this energy has a price tag and can also be a source of pollution, in the Netherlands we are trying very hard to improve ecological building performances.
This improvement does not always mean an improvement for the indoor climate and hence for the healthy environment for the people for whom after all the building is being erected.
Going back in history it is very surprising that similar, sometimes identical mistakes are made throughout the years. In this paper some of these mistakes are being analyzed and a small theory is developed in order to prevent these -un healthy, costly- mistakes.

Keywords: Durability, Healthy indoor climate

1 History

When in the end of the 19th century the masses of people began to migrate from the country-side to the cities a housing problem arouse. In Holland the wood was already being used for the shipbuilding in the 16th and 17th century so the mass of available clay deposed by the rivers soon made brick industry to develop. The usual method of brick construction consisted of solid brick walls of 200 mm (8-inch) thickness but sometimes brick walls of only 100 mm (4-inch) were build.

Brick can be seen for the Netherlands as a sort of ideal construction material. Due to its weight is has a large heat capacity, it can absorb water to a certain

Durability of Building Materials and Components 8 (Volume Three). *Edited by M.A. Lacasse and D.J. Vanier*. Published in 1999 by NRC Research Press, Ottawa ON K1A 0R6, Canada. ISBN 0-660-17742-0

The usual building method was cheap, no cantilevered roofs being used, walls as thin as possible. In the typical wet climate in Holland with lots of rain this resulted in water to penetrate into the wall and after long periods of rain the entire brick wall would become saturated, so the water could reach the inside of the building and even drop off at the inside, creating a very humid environment in the building, causing mildew and diseases for the inhabitants to develop.

The solution of this problem was quite simple, as the rain can't be stopped and a cantilevered roof was considered too expensive the phenomena of a wet brick simply was accepted. The 200 mm thick brick wall had to be divided into two 100 mm thick parts: the outside part acts as the integral water shield eventually absorbing excess rainwater and letting it drop off at the inside, the inside part of the wall will stay dry and thus creating a comfortable indoor space.
A small distance of some 50 mm (2-inch) separates the two parts, enabling the water at the inside of the outer wall to be either drained into the foundation or be ventilated away. The idea of the cavity wall was born.

Although the theory was known, and so the solution of the problem was clear, the building tradition was stronger and massive brick walls were still being build. The un-healthy over humid situation developed so bad that even government got involved and it was decided by law that dwellings had to be erected "using cavity brick walls" (Dutch Housing Law 1903)

Using this cavity wall the problem of humidity was solved.

1.1 Recent history

Energy was cheap in the 1950's and 1960's so the building style was a direct result from this situation: a low level of insulation as heating cost were not a major part of the operating cost of a building. Than suddenly in 1973 the world finds itself in a energy crisis, fuel prices go up, and as the buildings were not insulated well suddenly the fuel bill becomes significant.

As a consequence in order to save energy in Holland there is a national call for "The national hunt for cracks " as it is thought that these cracks form a major heat loss. Also large insulation programs are developed. The cavity spacing is remembered and filled up with insulating material, and within a very short notice the humidity problems arise again. This insulating material forms a bridge between the two brick blades and lets the water pass the brick wall.

Today the cavity brick wall still exist, but with a increased spacing allowing insulation material being placed in the spacing and yet still having enough room for a 30 mm (1.2 inch) spacing for proper ventilation.

This example shows that all the humidity problems of the 1970's could have been prevented by knowing and understanding the history and the specific characteristics of the cavity wall.

1.2 The healthy indoor climate

Since the basic reason for a building is protecting people from the outside climate it is necessary to define the situation that can be called a healthy indoor climate.

As it is obvious that this definition is rather complex and much more than simply the absence off illness, the following definition by the World Health Organization (WHO) is generally accepted :

"Health is the situation of entire physical, mental and social well being".

The question is how to create this situation and create at the same time a sustainable and durable living environment. The problem is creating a non-healthy indoor climate while doing one's best creating durable and sustainable buildings.

2 Learning from the past

Building durable and sustainable is partly focussed on a limited material use and a low or non use of materials that are considered to be not indefinitely available. So as a result of this wish for sustainable and durable building a list is made with materials to be used in only small quantities or preferably not at all due to the limited word wide availability.

The cavity wall example given in the introduction is in a way typical for the problem that arises when new ideas about building are developed without a full understanding of the behavior of the phenomena, changing the use of materials because of good intentions without entirely knowing the performance of these materials can bring similar problems as described in the case of the massive brick wall. A few other cases will be discussed.

2.1 Case copper

Copper is considered to be a material of limited availability and since the alternative for copper water pipes is easily and cheap available in the form of plastic piping, the use of copper can easily be minimized if not excluded.

In every dwelling water supply is necessary. In the old days lead was used, but some 50 years ago it was discovered that after some time the drinking water contains small amounts of lead resulting in health problems. So for new projects the lead is replaced by copper. Also a program is developed to change the existing lead water piping into copper, this program will take some time and is expected to be completed for more than 80 % in the Netherlands by the year 2005 (Dutch Ministry of Housing 1995)

Now the "Durability Wave" comes by and a consideration is to decrease the use of limited raw materials. Copper is considered to be such a material and soon the synthetic water piping is developed, and placed in many new housing projects. However after some time some of the inhabitants show health problems, it appears that the old copper piping was giving a very slight amount of copper to the water, just enough to keep the basic necessary amount of copper for the human body at the right level.

2.2 Case environment

It is commonly known that in Holland we have been fighting the water for years, in a rather successful way. We can say that there is almost no uncontrolled wet soil left. This has also lead to the extinction of the malaria mosquito (Anapheles atroparvus) giving the World Health Organization only as recent as 1970 the reason to declare the Netherlands as a "Malaria safe" country.

Now in order to create the "original" Dutch biosphere environmentalists recently proposed to give land back to the water and create new swamps.

It should be well considered that if we do so, we will also bring back the perfect living space for the mosquitoes an thus reintroduce the malaria parasite of the temperate regions (Plasmodium vivax and Plasmodium malariae).

2.3 Case Birds

In Holland is usual to cover the roofs of dwellings with ceramic or concrete tiles. Developments in tiling industry has produced cheap, but yet extremely accurate, very well fitting tiles giving even the smallest bird no possibility for the building of nests. Now a new developed product of the tile industry are special "Bird Tiles" in order to give this bird nesting possibility again. For some people suffering from allergic asthma this is a very bad development. Both the dust of birds feathers and the excrements of the mites living in the nests (Dermatpophagoides Glycypphagus to name a few) are highly allergenic and penetrate the indoor spaces. In addition blood sucking parasites may be introduced in bed rooms.

2.4 Case double glazing.

It has been stated before, the traditional house in the Netherlands was very poorly isolated. In new built houses double glazing and proper roof, wall and floor isolation has standard nowadays. If in an existing house the single glass is being replaced by double glass this often will make the building more airtight. If not properly ventilated this can cause an increase of humidity problems. The purpose of the double glass is an improvement in thermal isolation. It is sometimes forgotten that in this case this extra window isolation without extra floor isolation will result in a lower temperature for the floor, creating on floor level a relatively higher humidity, and if wall to wall carpet is installed this will create for the glycyphagus again very good living conditions.

3 Analyses

Unfortunately in all cases mentioned, in the end we can only say: we should have known.

A new situation/material/system is being created by professional, well trained specialist.

Yet new aspects not foreseen by these experts do arise. The resulting problems can only be solved if the consequences for the inhabitants are fully understood. In all cases it appears that health is a very important aspect.

4 Conclusion

These few examples can be made to a long list with similar items. The similarity in the cases is that with good sometimes even noble intentions a decrease of quality is reached and in the end it appears that we could have known before. In some cases this situation is unacceptable as in some/many cases it can also be stated that we should have known the consequences of our ideas. The problem is how to be sure to determine the consequences of the changes. The beginning of the answer is that analyzing and understanding the wider essence of our actions beyond the limits of building tradition will bring a wider view on what we are doing thus being prepared to improve our environment. In the future the tailored use of expert systems made available with modern ICT (Information an Communication Technology) should make it possible for architect and building engineers to have all aspects available when making choices. At Eindhoven University of Technology we started a cooperation of engineers and health technologists to construct such expert systems.

5 References

Dutch Housing Law (1903)
Dutch Ministry of Housing (1995), Dubo-centrum Utrecht

185 LIFE CYCLE ASSESSMENT AND THE DESIGN AGENDA: THE STANDARDS IMPERATIVE

A.R. Makenya,[1] D.P. Wyatt,[2] and G. Soronis[3]

[1]KTH-Royal Institute of Technology, Stockolm, Sweden, [2]University of Brighton, UK, [3]Swedish Building Institution, BST, Stockolm, Sweden

Abstract

Life cycle assessment (LCA) permits a holistic design supply chain management methodology. However, its introduction requires a fundamental review of the design agenda and the client supplier interface. Life cycle assessment (LCA) should be seen in terms of the strategic domain of each supply chain that goes to make up a building and the extent design agenda which embraces and secures environmentally acceptable, serviceable and life balanced buildings. The new ISO 15686 "Guide for Service Life of Buildings" (in the course of preparation) will provide a basis to promote a client culture for a design practice that includes guidance on supply chain of the whole life cycle assessment and auditing. Connecting the principles of LCA in this standard, it is believed that all relevant stakeholders should develop design agendas that encourage a life resource management through a defined reference period.

Keywords: Environmental supply chain audit, gate keeper, life audit, life cycle assessment, serviceability, standards, supply chain management.

1 Introduction

Today, the International Standards Organisation (ISO) community and world wide research activity is increasingly focusing upon developing sustainable development models, procedures and standards that can assist those who carry on business activities and processes in the built environment. Environmental management standards (Soronis 1997) provide organisations throughout the world with a framework, which helps to focus attention on process business activities and encourage acceptable environmental practices.

Durability of Building Materials and Components 8 (Volume Three). *Edited by M.A. Lacasse and D.J. Vanier*. Published in 1999 by NRC Research Press, Ottawa ON K1A 0R6, Canada. ISBN 0-660-17742-0

Whilst the opportunity to adopt a partial to full fledged life cycle assessment exists, (Eaton and Amato 1997; Erlandsson M. 1998), LCA has not yet become an integral part of the built environment decision-making process. Discussion, however, is under way to produce 'sustainable development' standards that will contribute to the design-construct-maintain phases in the built environment, especially life cycle assessment (Soronis and Makenya 1998). Here, where product life cycle assessment (ISO 14040 1996) has been developed, (especially in the Scandinavian countries), marked product and process improvement in the 'manufacturing domain' (Cemetata 1998) has occurred.

The principal Stakeholders and their design teams should now both recognise their supply chain management responsibilities and the central role in adopting LCA management, a responsibility that is beyond the current practices of the ISO 14040 series, and seeks to move their building programmes to a life framework. The problem (especially for those designing, building, developing and managing building portfolios) is how to implement a sustainable life practice, without being overly altruistic. In consequence, this paper sets out to review LCA and how it might be developed to become an integral part of the design agenda and supply chain management.

2 Life cycle assessment

Life cycle assessment (LCA) may be defined as "a procedure for evaluating the environmental impacts of a product, process or activity throughout its whole life cycle".

In that sense, LCA permits the evaluating of the consequences of the built environment demands upon nature in terms of exploiting those resources disturbed, marshalled, used, retained or discharged to landfill sites over time. In doing so, permitting the use of several measures including waste streams, gas emissions including CO_2 and embodied energy.

By inference, one is in effect setting out to determine the consequences of a course of action, from bringing a given material or component supply chain together in order to form a building to quantifying the environmental impact of decomposing that building into its probable waste streams and disposing of them over a defined period or periods of time. What some have in fact called the 'cradle to grave' cycle.

The cradle to grave time span can in fact be broken down into stages so that the material supply chain can be effectively appraised. It should be clear then that the built environment LCA details need to be understood in context of these stages, 2.1 to 2.7 below.

2.1 The supply chain processing phase

It is the exploiting of the natural resource base that conjures up environmental concerns and perceptions of the growing crisis of land fill constraints. In both respects, the principle stakeholders (the material producers and their end user developers) must understand the implications of their supply chain's life cycle and its impact upon a range of environments. In terms of material extraction and manufacture, the provider stakeholder utilises the following supply chain factors:

- **Factor 1:** 'Exploiting' a discovered resource domain. Here, natural ecological states, habitats and bio domains, that used to change in nature's time scales, are likely to be destroyed or changed dramatically for the worse in short periods of humankind activities.
- **Factor 2:** Exploiting or winning of the natural resource from its origin, often moving the resource to a processing location where conversion takes place to produce higher value materials or products. Alternatively, the extracted material-product is dispatched directly to an interim holding point (e.g. aggregate or sand merchant) or construction site.
- **Factor 3:** Having transported material to a capital invested fixed place processing centre like a factory or fabrication yard, here the material will become a designed product ready to be distributed, e.g. to stockists or direct to a given project site.

In a simple sense, one is talking about the supply chains or streams that permit the building activity to take place, anywhere and at almost any time on the planet. At the same time, concerns over greenhouse gas emissions from the principle stakeholders' activities' processes and subsequent distribution vehicle gas emissions, coupled with the scarring and damage of bio domains, do force both the provider and specifier to consider the impact levels of tolerance of their actions. It is, however, the client's building design agenda that may be seen as a key that forms the basis for the pursuit of environmental or sustainable building.

2.2 The design specifying phase

One may come to a considered view and say that it is here that the whole environmental failure of LCA occurs. Why? Because if the designer's design requires materials or components that contribute to the damage of a bio-domain, or a built environment suffers from that proposal, then the design brief's outcome is not environmentally compatible. The act of design and specifying might be seen as the 'actuator' that sets the damage parameters prior to building. It is therefore believed that LCA has an important part to play here in shaping future design agendas and briefs. In that sense moving to a life design:

- **Factor 4:** Design decision may be influenced by the construct of 'durability or service life quality concerns', or by a value judgement of acceptability against some performance-time cost based criteria.

At the same time, Stage 2.6 should become linked with or part of Stage 2.1, and recovery management anticipated both for an existing building standing and for the cannibalisation of its constituent parts. In that sense, the whole life resource management of a supply chain is shaped by the designer and their ability to blend the service lives before them (i.e. both new and used products and materials), as well as the more conventional measures concerning embodied energy and CO_2 calculations.

2.3 Construction phase

- **Factor 5:** This is the tangible outcome of the client brief and its execution - and of course where the supply chain is activated in a just in time or 'JIT' culture. Once work commences on site, environmental degradation and changes in the forest, hillside or in the ground, as materials and components flow to site in response to a material call off, are confirmed. The extent of the subsequent adverse impact depends upon the sustainable design quality. This impact can be reduced through re-crafting of existing buildings or reusing material and components.

In practice, the specifier's decision may well be changed during the project's planning and construction phase, as alternative suppliers at a lower cost are found, or packages are re-negotiated for a so-called value engineered solution. The key nature of this phase is that the supply chains are set in motion, materials and components marshalled and brought to their fixed point in the building project.

2.4 Life phase of the building

The respective ranges of materials and products, or incoming supply chains, become laminated into the building to form its construction. The client or building owner may wish to focus upon securing serviceability in the whole building stock, while the designer should maintain life buildability and good detailing in all project cycles.

- **Factor 6:** This stage that is undoubtedly the best understood LCA stage - in that sense one is familiar with the issues of maintenance and energy management, adaptation, retrofitting etc.

It is almost certain too, that the product's life of the formalised manufacturer's LCA work may become negated e.g. due to poor design life quality, end user or owners abuse, or simply neglect, or a change in expectation or demands, rendering the facility or system obsolete. In that sense, these are problems in any whole life assessment, nevertheless a design life agenda could flag up through on a 'what if' scenario basis!

2.5 Decommissioning

Whatever LCA benchmark is agreed upon, or used, it is inevitable that environmental standards will continue to change over periods of time. In consequence, design agenda should seek to minimise waste stream and seek to recover for reuse. The design agenda then would need to set the frame for re-configuration management.

- **Factor 7:** The LCA model adopted for dealing with existing buildings should be formalised and include the decommissioning stages. Here, the polluter's responsibility to pay principle has to be considered (as this is increasingly enshrined in legislation and case law). Such options or actions may impact upon both the clients building agenda and their brief or design agenda.

2.6 Dispersal and disposal

If no further use can be secured within the economic time frame of the building, and accepting the impact of rising landfill taxes and transportation costs, there may be, in the LCA model, need to develop new technologies for reprocessing or reclaiming used materials and components. In that sense, then, the outbound analysis may become an issue at either the performance scope or brief stage. This can be achieved by encouraging a responsive client, utilising an effective waste stream and recovery management. A strategy that may be supported by the emerging ISO 15686 Part 6 on LCA.

- **Factor 8:** The decommissioning phase, the serviceability status and option for alternative uses may become part of the design study. Likewise, inventory analysis of the in bound supply chain and options for local reuse, or alternatively insitu reuse as well or selling on the remaining service life, may be carried out.

2.7 Site reinstatement

The LCA would be expected to appraise the whole life of the design and likely rebuilding or future site use. In some instances, this evaluation may result in re-engineering or re-configuring substructure work and underground utility runs etc.

- **Factor 9:** In terms of LCA, the whole life cost must also include returning the site to a 'no worse condition than prior to development'.

3 Life cycle gates

Because of the act of specifying and -or developing a concept into life, LCA building appraisal needs a context in order to set out the sustainable framework that reasonably can be delivered. Adopting then a LCA approach poses an ownership problem, and to overcome this it is suggested that one should focus upon the time related domains. In doing so, adopting the simple construct of the gate and gatekeeper (Wyatt 1995).

So the key time gates proposed in a LCA and or resource management sense are then: *the cradle, cradle to gate, gate to gate or in service life period, gate to graveyard, the graveyard.* So, LCA might be more conveniently represented in terms of the following key stages:

- *Stage one:* Exploration, discovery exploitation, the bio-domain and ecological gate assessment i.e. pre-extraction and extracting to the exit- processing gate.
- *Stage two:* The in bound processing activity of the secured supply chain to be placed at the project gate.
- *Stage three:* Product life gate.
- *Stage four:* The exit gate to the terminal gate can both be complex, with recovery and reuse of materials and components through to building space

recovery and reconfiguration management. Here, decommissioning and re-commissioning may be linked. Further developments in unexpired service life may influence the decision of recovery at more than one level, as some manufacturers may decide to retain their materials e.g. steel frames or refurbish used components etc.

- *Stage five:* In this approach then the design agenda may embrace say through a performance based approach, the stage or stages their sustainable design will address. In that sense one now moves onto the gatekeeper again (Wyatt 1995).

4 Gatekeeper issues

Whilst the LCA built environment application may remain uncertain, it should be clear, however, that LCA is a methodical way of describing the presumed environmental impact for any one or more of the above stages identified (Lippiat 1998).

In consequence, the importance of introducing break point needs or control gates should be both accepted and acknowledged. In effect, these control gates have to be acknowledged, owned and managed if environmental impact assessments are to play a sustainable input in the way we are to build. Or indeed, to take care of what we have and replace the built environments, one must become clear in the context of the whole life building cycle activity, the building life and its supply chain domain.

In a sense then, one is looking at those who have a gate-keeping role to perform their duty in an accountable and responsible way. In consequence, deterring the design agenda would appear central to the built environment's own LCA, and the design brief must reflect the level of sustainable responsibility to the supply chain and its service lives arriving at the project's site gate. Indeed, the whole design agenda, in a sustainable sense, needs an urgent review and a whole LCA and Design Life guide prepared for all future project and design briefings.

5 The design agenda

As already implied above, central to that sustainable practice is the need to recognise the crucial role of the design life agenda, as the individual manufacturer's LCA only presents a part of the building impact upon the environment. The design agenda needs to reflect the terms of reference for the system boundary of the stages or phases identified above, especially where organisations are practising ISO 14000 and an effective EMS (environmental management system), for this must include their buildings and operational life building costs. In addition, both the probabilities of critical events being anticipated over long periods of time and the threat of obsolescence should not be trivialised nor ignored.

But in terms of the building owner, these areas may take on a serious future cost, if a carbon tax is introduced and/or site reinstatement an "environmental law" (regional or national). Or a delimiter is set- as to how much embodied energy can be disposed of.

The skills and judgement must in fact come from the designer integrating a design management that is ecologically sound and that, in a building life sense, optimises the life bearing properties of both the material supply chains as well as the existing built environment infrastructure and building stock. The design team, in all LCA-concepts, has to take into consideration the following aspects:

- Define their system boundary of the building's supply chain of material and components and accept the producer's LCA.
- Agree upon both precisions of the criteria and accuracy of the measurement used.
- Establishing the control domain and system gates for their own proposed laminations and service lives.
- Establish their buildings own gate keeper's domain including stages E and F (figure 1) which may not have been part of the normal design brief of the past.

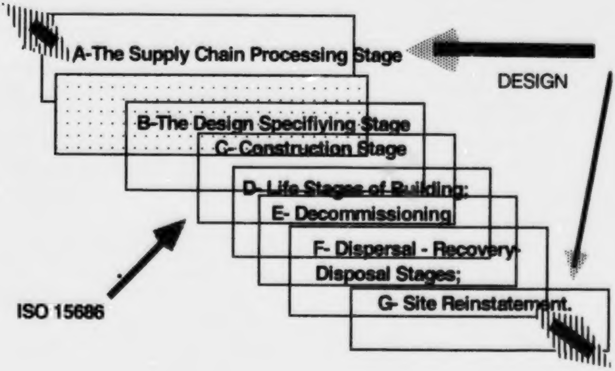

A-The Supply Chain Processing Stage
DESIGN
B-The Design Specifiying Stage
C- Construction Stage
D- Life Stages of Building;
E- Decommissioning
F- Dispersal - Recovery-
Disposal Stages;
G- Site Reinstatement.
ISO 15686

Fig. 1: The LCA (life cycle assessment) design domain

6 The design agenda stage

Designing for sustainable building runs the danger of being carried out on an ad hoc basis without LCA being an integral part of the design process. But LCA must be suitably scoped within a framework that leads to a consistency and a realistic application. At the same time, we must consider how we can access and replace parts of existing building systems, components and materials. The decommissioning stage has to include aspects on how to remove components without damage and how those components can be reused or recycled.

Table 1: LCA-stages and the gate control domain

	LCA Stages	Gate Control Domain	Key Holder
A	The Supply Chain Processing Stage	The cradle to gate	Manufacturing supply chain processor-and providers
B	The Design Specifying Stage		Design Appraisal
C	Construction Stage		
D	Life Stages of Building	Gate to Gate or in service period	Asset and Facilities Management
E	Decommissioning		
F	Dispersal - Recovery-Disposal Stages Final Rest Place	Gate to graveyard The grave yard	Recovery Management
G	Site Reinstatement	A cradle for future building or return to nature	Owner

The framework's life cycle assessment's design agenda characterisation needs to be better understood, as it appears there is a degree of unthinking or discounted stewardship. There is then a case now to focus on moving from the project focus to a product focus. In doing so, recognising the design team is in effect, without patrons, the building product champions (Wyatt 1995). In consequence, it may well now be the time to develop a design agenda framework which addresses the broken gate system shown in Table 1.

So the whole life- supply chain objectives would be then to secure a building or product, design or construction life, which in a LCA sense would also include:

- Focusing on being project specific product and building disposal matters Identifying the criteria-environmental and design or service life reference audit stages intent.
- A suggested programme for each LCA cradle to project gate material group or system appraisal.
- In operational gate to audit life documentation needs as well as for stages E and F in Table 1.
- Guidance on formulating the sustainable development performance specification and design audit stages e.g. concept, packages, commissioning as well as life care planning requirements etc.
- Guidance of recovery an existing building rather than build new whilst at the same time pressing ahead with the open building system under development.

7 Conclusions

Materials and components are for life. A view, which will impinge directly upon the design agenda and those that supply the built environment with material components and design, construction and life care services. Indeed, an inherited liability until such time as it can be replaced within the context of any CO_2 delimiters set within a future date. The LCA (life cycle assessment) model may be best seen assume form of systematic process frameworks with a sustainability feelings but avoided like the other terms like green and sustainable. Further, one can consider LCA characterisation responding to:

- Non-renewable resources depletion including environmentally damaging extraction developing or recovery processes which lead to ecological damage or loss of diversity of natural habitats.
- Recovery management or use of previously used materials or components.
- Conservation in that sense of managing the durability of an existing building stock.
- Service loss and recovery of such loss.
- The loss of serviceability in an asset management sense to improve briefing on life care scoping.
- Service life as a central design issue in a sustainable construction sense.
- Embodiment within a $C0_2$ and associated negative gas releases on cost to the environment.

The challenge then will be for designers, however, to translate the desirable LCA objectives into workable solutions as the gatekeeper at their project gate and the one that waves farewell to the life of their new creation. In consequence it is perhaps best to address LCA at two distinct levels:

- **Level 1:** At the macro level where the industrial relational architecture can evolve and attention to renewable and non-renewable resources can be closely appraised.
- **Level 2:** At the product level, always considering the deconstruction and think how we can reuse products and materials to secure a recycling chain reaction.

Supply chain management becomes central in all building designs. What is now hoped for is that one of the parts proposed for the ISO 15686 now under development will address the LCA relationship to contribute to the pursuit of life design. In doing so, seeking to: "provide guidelines to encourage the use of service life planning to meet the design life of the building, taking into account LCA of the respective incoming and out going supply chains in any building being designed for, or being removed from, the built environment".

According to ISO 15686, Service Life Planning of Buildings means selection of materials and building components by optimising their service lives to meet the client´s performance requirements for the building design (including cost performance). By using LCA- analysis in service life planning of buildings, the designer can optimise the service lives of the materials and components not only by a common business economic/ technical optimisation, but also by taking into consideration environmental aspects as e.g. recycling of materials, impacts on the environment, energy and mass consumption etc. For example, the designer can choose less durable materials with sometimes higher initial costs and still have an optimal design (by taking into consideration environmental aspects). *The opposite statement* is also very important in all LCA-analysis: LCA involves consideration of durability and service life planning of buildings and building components. Thus, it is impossible to find the LCA-optimum without involving service life planning techniques in all building designs.

8 References

Cementa. (1998) Environmental Impact of Concrete Analysed. Danderyd, Finland.

Construction and the Environment. (1998) *CIB Congress, Gävle, Sweden*, p. 8.

Eaton, K and Amato, A. (1997) Life Cycle Assessment. New Steel Construction Aug./Sept., p. 2.

Erlandsson, M. (1998) Environmental assessment method adapted to buildings. *CIB 1998 Congress, Gävle, Sweden*. Vol. 2 Symposium A, pp. 913-920.

ISO 14001. (1996) Environment Management System.

ISO 14040. (1997) Life Cycle Assessment.

ISO 15686. (1998) Service Design Life of Buildings Guide.

Lippiat, B. (1998) Building Environmental and Economic Sustainability (BEES) *CIB 1998 Congress, Gävle, Sweden* Vol. 2 Symposium A, pp. 787-799.

Soronis, G. (1997) International Standardisation for Sustainable Building. *Proceedings of the Second International. Buildings and The Environment. CIB Task Group 8, Paris*, pp. 503-507.

Soronis, G. and Makenya, A.R. (1998) Towards a new integrated ISO standard for sustainable building. *CIB 1998 Congress, Gävle, Sweden*, Symposium A, pp. 467-471.

Wyatt, D.P. (1995) The Unhappy Gatekeeper. *The International Journal of Architectural Management Practise and Research*, pp. 71-79.

Wyatt, D.P. (1995) Project of Product Management. *The International Journal of Architectural Management Practise and Research*, No. 10, pp. 151-160.

186 LCA AS PERFORMANCE REQUIREMENT IN THE DUTCH BUILDING DECREE BY 2001

N. Scholten

TNO Building and Construction Research Institute, Delft, The Netherlands

Abstract

In February 1998 the Dutch government decided to implement sustainability requirements by the year 2001 in the Dutch building Decree. Part of these requirements shall be a performance requirement for the environmental influence of the total use of materials, determined by LCA (life cycle analyses), for dwellings or residential buildings.

In order of the Ministry of Housing, Physical Planning and Environment, TNO develops the determination method for that requirement and advises the Ministry about the performance criteria.

The determination method shall be performance based. In the method a solution shall be given for:

a. modelling a dwelling or residential building in streams of materials at the stage of a building permit, a moment that not all decisions about specifications of materials are taken;

b. modelling of the streams of materials for building elements which are necessary to get a permit and modelling of streams of materials which are not part of the building plan but can be build later on, free of a building permit;

c. modelling of the streams of materials of combined buildings (a dwelling and other type of building like a offices which dwelling and other building together are one work);

d. the environmental model to calculate the environmental effects of the materials used during the lifetime of a dwelling or residential building;

e. differences in results due to different types of dwellings or residential buildings (differences in floorarea, differences in appearance and so on); calculations rules have be developed toto recalculate the results to an entity to which entity in the Decree performance criteria shall be given.

Keywords: performance requirement, regulation, determination method, materials, construction, standards

Durability of Building Materials and Components 8 (Volume Three). *Edited by M.A. Lacasse and D.J. Vanier*. Published in 1999 by NRC Research Press, Ottawa ON K1A 0R6, Canada. ISBN 0-660-17742-0

1 Research project

The project has been started in October 1998 and shall be finished mid 1999. In the conference a state of the art report shall be given of the on going research project. The results of the project will be presented.

The question to be answered is to develop an unambiguous determination method for the environment-performance-profile of the total use of materials ("mpm"), determined by the LCA-method, of a dwelling or residential building. The method must fulfil the juridical criteria, which are the foundations of the Dutch Building Decree. The background of this Decree is given in annex 1. The method will be part of the building permit procedure of a dwelling or residential building after the year 2001.

The research project have been split in two phases. Phase 1 is the pre-study. This phase will end mid 1999. In phase 2 the determination method will definitively be written down in a one or more standards. Phase 2 shall be ended at the end of 2000.

To get the necessary determination method a modular study is planned. The determination method will have three main elements:

1. Modelling a building in three material streams, production stage of building products, erecting and exploitations stage of a building and the stage of demolishing and waste materials, ;
2. Calculation of the environmental effects of the total use of materials, based on the LCA principle, for the three material stremas, and
3. developing databases with needed figures.

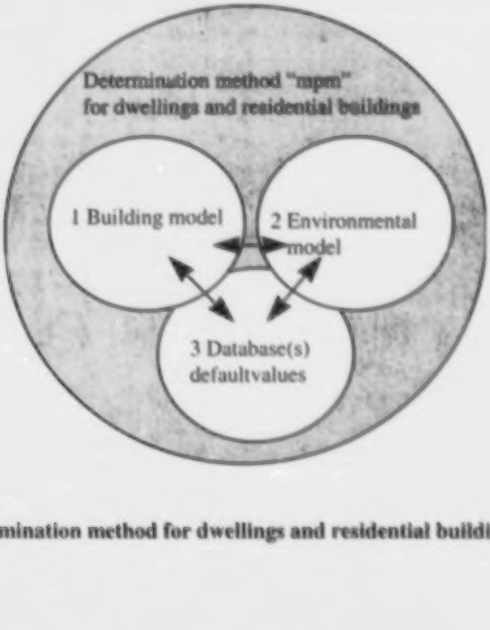

Determination method "mpm"
for dwellings and residential buildings
1 Building model
2 Environmental model
3 Database(s) defaultvalues

Fig. 1: Determination method for dwellings and residential buildings

Justice given to the conditions of the Dutch Building Decree the research project will lead to a determination method to calculate the environmental-performance-profile of the total use of materials of a dwelling or residential building ("mpm"). The method shall be used in the stage of a building permit.

The pre-study will have two steps, which both steps have different study-objects:

a. step 1
  - study of modelling a building in streams of materials;
  - study of environmental objects;
  - study of legislative objects, and
  - an integration study of modelling, environmental aspects and legislative aspects.
  -

  The end result of step 1 shall be a rough description of the determination method and an overview of white spots to be solved.

b. step 2
  - developping a rough prototype of the determination method;
  - studies to solve the white spots, and
  - develop a more detailled prototype.

The study will be based on the different instruments which already are used in experimental practise like Eco-Quantum, Eco-Install, Twin, Greencalc, ATHENA, BEES, CAAD, BREEAM, GBC, MRPI, LCA2, ISO-standards and developments of CEN, CETAC, CIB and others.

During the first step of the pre-study these instruments will be judged in relation to legislative use during a building permit procedure in the Dutch context. This will lead to white spots to be solved. The second step will lead to a rough model of the determination method. In that step also the white spots will be solved in a legislative, well-balanced way.

2 Research team

The researchproject will by done by a consortium. The leader of the Consortium is TNO Building and Construction Research at Delft. Members of the Consortium are:

- IVAM, University of Amsterdam;
- CML, University of Leiden;
- TNO, Environmental research at Apeldoorn;
- Intron bv at Geldermalsum, and
- W/E at Gouda.

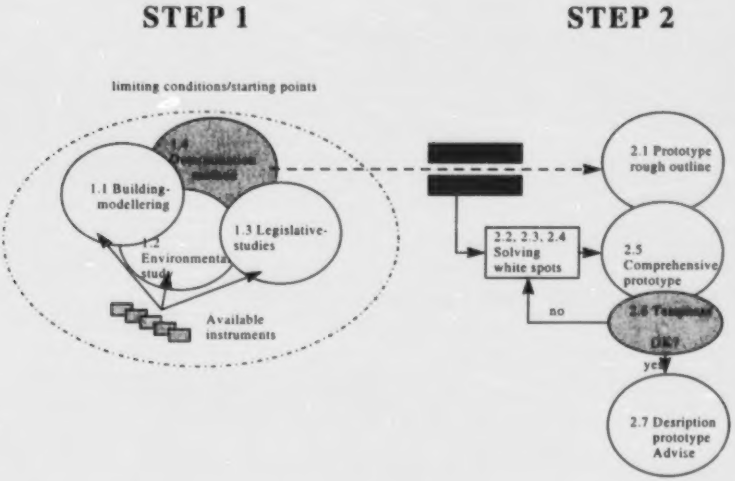

STEP 1
STEP 2
limiting conditions/starting points
1.4
1.1 Building-modellering
1.2 Environmental study
1.3 Legislative-studies
Available instruments
2.1 Prototype rough outline
2.2, 2.3, 2.4 Solving white spots
2.5 Comprehensive prototype
2.6
OK?
no
yes
2.7 Desription prototype Advise

Fig. 2: Determination method to calculate the environmental-performance-profile

3 Performance based building regulations in the Netherlands

3.1 History

Before 1 October 1992, the technical building regulations in the Netherlands were subject of:

- The Housing Act;
- some 700 local building by-laws;
- local Connection Conditions for electrical energy;
- local Connection Conditions for gas;
- local Connection Conditions for drinking water;
- Dutch standards concerning private agreements for several technical issues as good practise, but outside the formal regulations;
- quality-approvals as good practise but outside the formal regulations;
- several non-interrelated laws and decrees.

Although these by-laws were based on a Model Building By-law, considerable disparities remained between them. This and the structure of the municipal requirements caused a lack of uniformity in the regulations and to the application. As for the structure of the requirements, the by-laws mainly contained the so called 'functional requirements' and other regulations with possibilities for further requirements and exemptions.

In 1983, the dissatisfaction with the technical building regulations and the long time decisions on building permit applications often took, led to the drawing up of an Action Program for Deregulation of the (House) Building regulations. The Minister of Housing, Physical Planning and Environment announced in this Action Program, among other things, a national Building Decree and an obligatory maximum term of three months for the decision on a building permit application. The technical regulations regarding the internal lay-out of buildings would be given a global nature, and the technical building regulations would be rendered uniform.

3.2 The Dutch building regulation system after October 1992

In the Dutch building regulation system, the Building Decree is the central document for the technical building rules. Based on the Housing Act, that does not contain technical rules, the Building Decree is a general administrative order, issued by the central government.

With regard to some subjects, the Decree authorises the Minister of Housing, Physical Planning and Environment to give further rules by ministerial order, namely:

- rules concerning the application of standards and connection conditions which have been referred to in the Decree. The intention of this authorization (section 416) is that the ministerial order indicates which edition of the standard or which part of it, or which edition of the connection condition is applicable. In this way a swift and flexible anticipation to the regular revisions of these documents can be effectuated;
- regulations containing technical requirements for a number of specified building aspects. There are different reasons for these authorizations. At the time the Building Decree was laid down, it was clear that for some subjects it was not still possible to give regulations in the Decree itself, e.g. because the indicated standards did not already take account of existing buildings. Further, for other subjects it was intended to create a possibility to give regulations when needed, e.g. for occasions that the harmfulness of a material becomes clear. Also here the fastness and flexibility of regulation by ministerial order plays a part;
- rules concerning the implementation of the Construction Products Directive of the EC.

In the Building Decree, standards play an important role. Wherever possible the Decree refers to standards ('NEN's') or parts of standards of the Dutch Standardization Institute. These standards have been adapted to the Building Decree requirements and contain the determination methods intended to check if the work complies with the Building Decree requirements. There are 47 standards the Decree directly refers to.

3.3 Structure of the building Decree

The structure of the Building Decree, in particular the structure of its complex of technical regulations, has been determined by three grouping criteria, to wit:

1. the distinction between usage functions (or types of works);
2. the distinction between works to be constructed and existing works, and
3. the so-called starting points for laying down building regulations.

This design has been chosen for the purpose of enabling the users of the Decree to find efficiently the relevant regulations and to see at a glance what the intention of these regulations is.

Concerning the usage functions, conceptually the main distinction lies between construction works which are not intended for living in and other works. The latter can be distinguished in houses, residential buildings and caravans and sites. The other group -of 'utility works'- comprises both buildings and works not being buildings.

The effect of this distinction on the subdivision of the Decree is such that for each usage function there is a complex of regulations. Each complex comprises two chapters, viz. one for works to be constructed (new or alteration) and one for existing works. The regulations for buildings not intended for living in are being further elaborated in the current second phase of drawing up the Building Decree. At present, there is one complex with general regulations for all 'utility buildings' (chapters VI and VIII), and two with further regulations for special usage functions (chapters VII and IX). Only for office and accommodation buildings, both the general and the further regulations apply.

As to the third aforesaid grouping criterion, this has determined the structure within the chapters. The regulations are ordered in separate divisions, according to the main starting point or intention from which they have been given. As mentioned before, there are four of such starting points, viz. safety, health, usefulness and energy economy.

For existing buildings there are no regulations from a viewpoint of energy economy. The reason for this is, that in consideration of acquired rights (formerly obtained building permits) such regulations would be too far-reaching. For construction works not being buildings, pursuant to the Housing Act, there are no regulations from the viewpoints of safety and health.

3.4 Performance requirements

The technical regulations of the Building Decree are expressed in performance requirements. In a regulation, the performance requirement is based on a functional definition. This definition expresses the intention of the performance requirement. The performance requirement consists of a limit value and a determination method. By the limit value, the level of performance is indicated that minimally has to be attained. As stated above, for the determination method the Decree usually refers to a standard of the Dutch Standardisation Institute.

For example, an analysis of section 70.1 gives the following result, in which the performance requirement is printed bold, the functional definition underlined and the determination method normal.

> "**An external partition construction of a staying area, a toilet room or a bathroom**, *in order to restrict loss of heat by transfer or conduction*, **shall have a thermal resistance of at least 2,5 m^2×K/W**, determined in accordance with NEN 1068."

This way of formulating the regulations results from the aforementioned Action Program for deregulation. Briefly, the criteria are that a regulation has to ensure an optimal legal certainty and equality, must be unambiguous and thereby measurable and verifiable, and only in the smallest possible degree may restrict freedom and innovation.

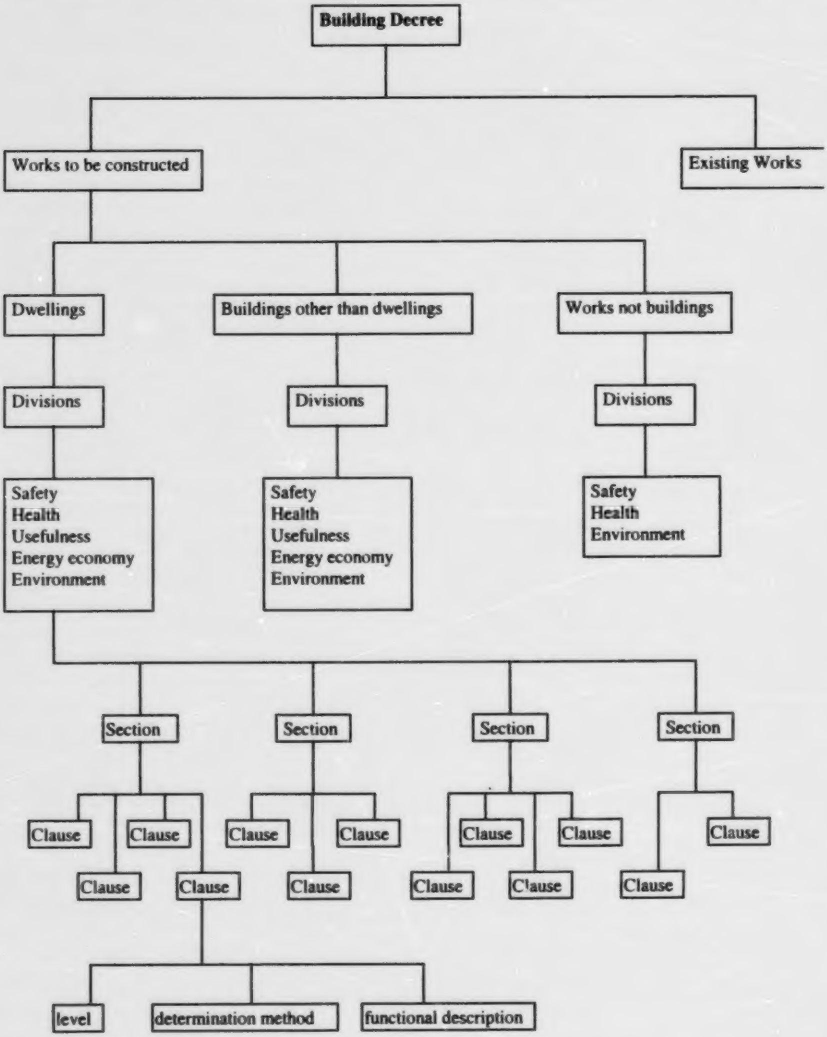

Building Decree
Works to be constructed
Existing Works
Dwellings
Buildings other than dwellings
Works not buildings
Divisions
Divisions
Divisions
Safety
Health
Usefulness
Energy economy
Environment
Safety
Health
Usefulness
Energy economy
Environment
Safety
Health
Environment
Section
Section
Section
Section
Clause
level
determination method
functional description

Fig. 3: Structure of the Decree

3.5 Relations between documents

Performance requirements let the builder free in the way he will comply with them. This means there are no so-called 'deemed-to-satisfy' prescriptions. Still, there is a practical need for instructions for indication how to comply by means of current constructions. This need is met by so-called 'NPR's' (Dutch Codes of Practice), which mentions the measured or calculated performances for these constructions. The Building Decree does not refer to these NPR's, but they have been developed on the basis of standards referred to in the Decree.

Other regulatory documents the Building Decree refers to are the Model Connection Conditions of the associations of public utility companies. Quality approvals are an efficient way to check if constructions, construction products and materials comply with the requirements. The Building Decree provides that quality approvals that are recognised by the Minister of Housing have to be accepted as sufficient proof of compliance with the performance requirements (section 415).

Figure 4 represents the relation between the Building Decree and the mentioned documents.

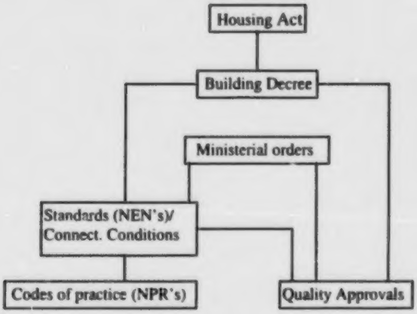


Fig. 4: Interrelation between documents

3.6 Equivalence provision

Performance requirements allow an amount of freedom in designing a construction work that is maximal when adhering to the criteria of unambiguity etc. of the requirements. However, it may occur that a solution in a building plan that is, being judged on its own merits, not inadmissible, does not fit to one or more requirements. The reason of this could be the nature or the situation of the construction work or the application of innovative materials or constructions.

For these cases the Building Decree contains the so-called equivalence provisions. Each division containing technical regulations ends with stating such a provision. If the applicant for a building permit wishes to opt for such an uncommon solution, he will have to demonstrate to the municipality that this solution corresponds with the intention and the level of the performance requirement of which limit value or determination method he wants to deviate from. Consequently, the equivalence concept does by no means serve to make possible the use of solutions of a lower quality level. The applicant may demonstrate the equivalence, e.g. by submitting a quality statement or a relevant scientific publication. He must take into account that the treatment of such an application takes more time than in regular cases.

3.7 The progress of the Dutch building Decree

A lot of developments have been occurred since the introduction of the Building Decree (1992) and the three amendments concerning the CE-mark, Energy Performance and Lifts.

As they announced, the Ministry of Housing has worked out the second phase of the Building Decree. Furthermore, inquiries have been hold concerning the evaluation of the Housing Act and the Building Decree.

International developments, however, induce to adaptations. Next to this, a government policy has been developed relating to:

1. further integration of disabled people (accessibility);
2. a better protection of the environment (sustainability), and
3. improvement of laws by regulation of only essential requirements and let freedom to market mechanism as much as possible, deregulation and the quality of legislation.

4 References

Final report of CIB Task group 11 *Performance-based building codes*, CIB Report, Publication 206, April 1997

Dutch Building Decree, Staatsblad 1991, 680 with all amendments, latest Staatsblad 1998, 619.

Strategische verkenning naar de mogelijke rol van normalisatie bij Duurzaam Bouwen, NNI, May 1998

Plan van aanpak duurzaam Bouwen in de bouwregelgeving, letter DBD-98048311/Z2016250, 4 June 1998, Ministry of Housing, Spatial planning and Environment.

Handleiding voor het opstellen van milieurelevante productinformatie, ref SNPR98001, versie 1.1, July 1998, Foundation NVTB Projecten SNP

Haas, Michiel:(1996) *TWIN- Model, Environmental assessment model for buildings*, these, The Netherlands.

Heijungs, R. *et al.* (1992*) Environmental life cycle assessment method of products*, Centre of Environmental Science Leiden, The Netherlands.

Mak, J.P., D.A.F., Kortman, J.G.M..(1996) *Eco-Quantum, final report: design of a calculation method to determine the environmental load of a building in a quantitative way* (in Dutch), Gouda, The Netherlands.

Mak, J., Anink, D., Knapen M. (1997) *Eco-Quantum, development of LCA, based tools for buildings*, in Proceedings of CIB Conference Task Group 8, Buildings and the Environment, June 9-12 Paris, France.

187 USE OF SERVICE LIFE DATA IN LCA OF BUILDING MATERIALS

S.M. Strand[1] and P.J. Hovde[2]

[1]Norwegian University of Science and Technology,Trondheim/Norwegian Building Research Institute, Oslo, Norway, [2]Norwegian University of Science and Technology, Tronheim, Norway

Abstract

The time horizon in Life Cycle Assessment (LCA) depends on the product being studied, and on the goal definition of the LCA. Service Life Prediction is the prediction of service life under specific conditions, as found in service life models or testing. The study reported in this paper was undertaken with the purpose to show how service life data are needed in LCA, how the data occur and how they influence the result. Wooden cladding and brick veneer are the external wall materials included in the study. There is a large variation in the environmental load, calculated from LCA, for the different scenarios. This study shows that in order to use LCA as a tool to evaluate the environmental quality of different products, it is important to assess the surroundings in which the materials are used, and the maintenance of the materials during use.

Keywords: LCA, Service life, building materials, service life estimates

1 Introduction

Life cycle analysis (LCA) is a systematic survey and evaluation methodology of health-, environmental- and resource effects, throughout the lifetime of a product. The lifetime of a product or product system extends from extraction of raw material to final treatment of the waste, as illustrated in Fig. 1.

Durability of Building Materials and Components 8 (Volume Three). *Edited by M.A. Lacasse and D.J. Vanier*. Published in 1999 by NRC Research Press, Ottawa ON K1A 0R6, Canada. ISBN 0-660-17742-0

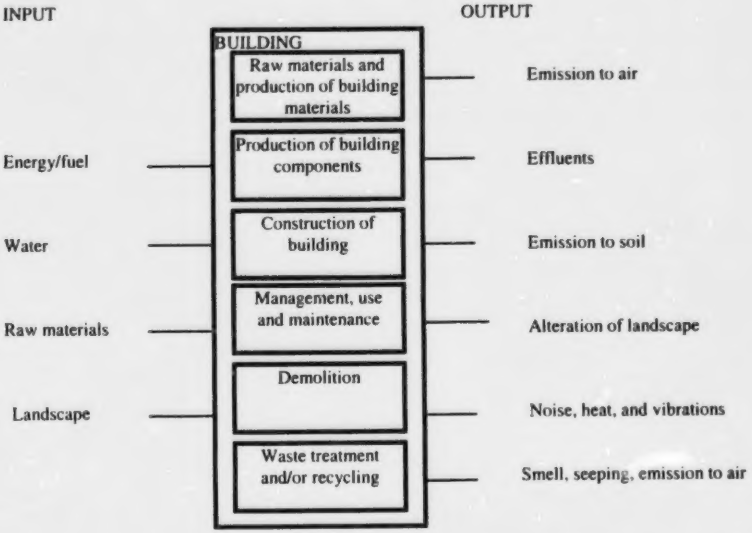

INPUT
OUTPUT
BUILDING
Raw materials and production of building materials
Production of building components
Construction of building
Management, use and maintenance
Demolition
Waste treatment and/or recycling
Energy/fuel
Water
Raw materials
Landscape
Emission to air
Effluents
Emission to soil
Alteration of landscape
Noise, heat, and vibrations
Smell, seeping, emission to air

Fig. 1: The different steps in the life cycle of a building in relation to raw materials and output (Strand 1996)

The main structure of a LCA, as set out in ISO standard 14040 is (Hanssen 1997):

1. Goal definition and scope
2. Inventory analysis
3. Impact assessment: classification, characterisation and valuation
4. Interpretation

Goal definition and scope involves determining of the purpose of the LCA, it's limitations and assumptions, data quality assessment, definition of Functional Unit (FU) and organisation of the work. The FU should reflect the purpose of the analysis, this will therefore have consequences for the results from the LCA (Hanssen 1997). Further Functional Unit aims to describe the service of the product quantitatively as well as qualitatively, with focus on the duration of the service. As a building and its building elements have many services, it is difficult to select one property to define the Functional Unit. A common solution has been to define a service life of for example 50 years with defined maintenance procedure or standard to be maintained (Krogh 1997).

LCA results are used in various types of characterisation systems for building materials and components (Larson 1997). Labelling systems like "Svanen" ("The Swan"), in Norway, result in a situation with no possibility of comparing the labelled products with each other, in order to choose the best alternative. A declaration system gives information about the production of the material (country, transport, recommended use, raw materials, toxic compounds, energy use in production and use, packaging), use and return systems together with reuse and recovering potential. Building products are often evaluated by determining their environmental load on the basis of these declaration systems. Evaluation of a material can also be based on LCA, taking into consideration service life and durability properties, energy use, emissions and effluents.

All the methods mentioned above are more or less based on LCA, or at least the LCA way of thinking. Many methods underestimate the user phase, which is particularly important when dealing with building materials. The reason for this underestimation is most likely the difficulty of dealing with long time horizons. These problems, and the importance of finding a way to handle them, are discussed in the rest of this paper.

2 Service life data in LCA and LCA based characterisation methods

In this part of the study, time horizon and input data in LCA are related to service life prediction methods and the input data required in these methods. For different definitions of service life, see the standard ISO/CD 15686-1 and 2.

2.1 Time perspective in LCA

The time horizon in LCA depends on which product is studied and the goal definition of the LCA (see section 1). LCA was originally used to study "simple" products like disposable diapers, drinking cups and packaging. Often the user phase in these cases is assumed to be the short number of years where the product is used, based on manufacturer experience and knowledge of market needs/behaviour. This is also often correct for consumer goods, because we have statistics helping us to "predict" the use of the products, for example for cars.

Building materials and components are used for a longer period of time than most other products. LCA of a building product therefore necessitate gathering of data will be valid for a longer period of time (Jønsson 1995). The building, building components and building materials also have different life spans. For materials used for surface layers, service life will be shorter than for the materials in the rest of the building.

2.2 Input data in LCA

When undertaking an LCA of building materials, components or a building as a whole, data have to be collected for all the phases shown in Fig. 1. The inputs and outputs in Fig. 1 are the input in the LCA. The life cycle of the building can be seen as a collection of many life cycles of different materials and components of the building. The durability and the course of these individual life cycles also depend on each other.

2.2.1 User phase in LCA

The user phase in the LCA of buildings is often only registered as energy use. The energy use of a building is also the single most important factor contributing to the environmental load from a building. It is also a fact that about 40 % of the world's material resources are used in buildings. This makes it important to optimise the use of building materials. For each material and component information about the use, maintenance and replacement are important to assess the environmental consequences. If some processes are left out of the study, it is important to include a description of these processes. The cleaning methods, types and frequencies of maintenance and replacement associated with the product must be described. Emission related to these processes, together with emission from the material itself must be listed. The expected service life of the material/component is included in the analysis usually reflected in the functional unit (FU). In different evaluation methods for buildings, problems concerning service life have been recognised, and dealt with in different ways (ENBRI 1997, Cole and Larsson 1997).

2.3 Input to service life prediction

Service Life Prediction (SLP) is the prediction of service life from recorded performance over time as found in service life models or testing. Part 1 of ISO/CD 15686 describes the general principles of service life planning and Part 2 describes the methods of service life prediction of materials, components and assemblies in specific conditions. In the Draft ISO Standard, service life forecasting, service life prediction based on test data and the factor method for estimating service life, are presented as three principal methods to predict service life of a material. This paper does not repeat the different methods in detail, so the reader is referred to the draft standard for further study.

This study has not made use of test data or recorded performance, the factorial method will therefor be used as a systematic method of estimating service life of the materials in specific conditions. The factorial method uses the following modifying factors:

- A: Performance of materials
- B: Design level
- C: Work execution level
- D1: Indoor environment
- D2: Outdoor environment
- E: In use conditions
- F: Maintenance

The factor influence on the reference service life is calculated as shown in equation one.

$$ESLC=RSLC*A*B*C*D1*D2*E*F \qquad (1)$$

Where ESLC = Estimated service life of the component
RSLC = Reference service life of the component

Not all the factors have been included in this study. Instead the focus has been on factors D2 and F. ISO 6241 summarises the environmental degradation agents affecting factor D2 as:

- Thermal agents like heat and frost
- Mechanical agents like wind, hail, snow etc.
- Biological agents, like micro organisms, fungi and bacteria
- Electo-magn. agents, like solar radiation (UV) (IR)
- Chemical factors like moisture, rain, condensation, pollutant, dust etc.

It is recognised that the selection of factors affects the estimated service life, and the result from the LCA, but it is evaluated as adequate for the purpose of this study. The modifying factors are set according to the Reference State. From the previous chapter we see that the basis for SLP also has to be included as a part of the LCA base, together with the results from the SLP.

3 The LCA sensitivity towards service life data

The influence of service life and service life data on the results from LCA is a topic that deserves more attention. Many scientists have discussed the problems, and there is ongoing research regarding prediction of service life. This paper attempts to see the need of correct service life data, and the practical use of this data. The study itself is theoretical, hence not based on field studies, but real life scenarios are constructed as far as possible, to approach practical problems in performing an LCA of building materials.

3.1 LCA cases

The software program SimaPro is used to determine in broad terms, the importance of estimating the correct service life of a material. It must be stressed here that when applying this technique on building materials, the purpose was not to determine which is the best material, or in any way try to perform a *complete* LCA. The study was performed with the only purpose to show how service life (SL) data are needed in LCA, how the data occure and how they influence the result.

3.1.1 Goal definition and scope

Exterior walls are a part of the climatic shield of a building, together with roof construction and windows. The insulation performance of these building parts affect the energy use in the building. This energy use will normally be a part of an LCA. The surfaces of building elements can be maintained without any severe treatment of the element itself. Surfaces can therefore be considered as independent of the building element, and thereby be treated in a separate LCA. For example this study treats the exterior cladding of a wooden wall construction in separate LCA's. The construction behind the cladding is not included. Materials included are wood cladding and brick veneer, and the analysis is limited by the available data. Most data used are collected from Pré4-, BUWAL250-, IDEMAT96- and IVAM-databases, for further description of data quality etc., see the database manual from PRé Consultants (1997).

3.1.2 Inventory

The Functional Unit in this study is 1m^2 wall, maintained at regulat intervals, during the technical service life of the exterior wall covering. Most processes linked to the production, maintenance and tearing down of the cladding are covered in this study. Emissions during use from the materials and the cleaning methods are not included.

The following materials and processes are included:

1. Wood cladding
    a) Production of pine.
    b) Transport of wood panel to the building site.
    c) Nailing
    d) Maintenance: Removal of paint and cleaning of wooden wall
       Painting
       Reparation by changing some of the boards
    e) Incineration after tearing down
2. Brick veneer
    a) Production data for bricks and brick mortar
    b) Transport of bricks and mortar to the building site
    c) Maintenance: Acid cleaning of the veneer after the lying of bricks.
       Re-doing of joints (only material production data)
    d) Recycling of materials after tearing down

Table 1: Scenarios for Wood cladding (numbered from 1W to 8W), with the resulting service life (SL) and environmental load from LCA. All numbers are in years, if not stated otherwise.

NR.	Climate	Facade facing	Painting interval	Cleaning interval	Replacement interval	SL	Points	
							(mP/m^2)	(mP/m^2 year)
1W	Industrial	North	5	5	-	35	83,3	2,38
2W	Industrial	North	10	10	-	32	54	1,68
3W	Industrial	South	4	4	25	42	125	2,99
4W	Industrial	South	8	8	-	28	54	1,92
5W	Rural, inland	North	8	0	30	63	94	1,49
6W	Rural, inland	South	8	0	-	55	85,25	1,55
7W	Rural, inland	North	10	0	-	50	62	1,24
8W	Rural, inland	North	12	0	-	40	52	1,29

The scenarios used in the study are listed in Table 1 and Table 2. The factor method is used to make estimates of service life. see section 0 below. In Table 1 and

Table 2, Points (P) refers to Eco-indicator 95, which is an evaluation system based on distance-to-target principle. The assumption behind this evaluation system is that the seriousness of an impact can be judged by the difference between the current and a target level (PréConsultants 1997).

Table 2: Scenarios for Brick veneer (numbered from 1B to 4B), with the resulting service life (SL) and environmental load from LCA.

NR.	Climate	Facade	Re-doing of joints, interval	Cleaning interval	SL	Points	
						(mP/m^2)	(mP/m^2 year)
1B	Industrial	North	30	10	120	39	0,31
2B	Industrial	North	60	20	90	371	0,30
3B	Rural, inland	South	30	20	150	28	0,26
4B	Rural, inland	North	60	30	120	27	0,24

(All numbers are in years, if not stated otherwise)

3.1.3 Service life estimates

The service life of a brick veneer is complicated to evaluate because of good durability of the material. The technical service life of the material may be longer than the service life of the building as a whole. The service life is estimated using the factorial method described in section 2.3. The modifying factors evaluated are outdoor environment, including pollution level (D2.1) and facade direction (north or south) (D2.2), maintenance (F), including painting interval for wood panel(F1) or redoing of joints for brick lining(F1), replacements(F2) and cleaning(F3). The resulting ESLC for wood cladding and brick veneer are shown in Table 3 and Table 4, respectively.

Table 3: The calculation of ESLC in the different scenarios described in Table 1

	ESLC	D2.1	D2.2	F1	F2	F3
RSLC	50	1	1	1	1	1
1W	49	0,8	1	1,12	0,92	1,2
2W	32	0,8	1	1	0,8	1
3W	42	0,8	0,7	1,22	1,02	1,2
4W	28	0,8	0,7	1,1	0,9	1
5W	63	1	1	1,1	IR	1,14
6W	39	1	0,7	1,1	IR	1
7W	40	1	1	0,8	IR	1

Table 4: The calculation of ESLC in the different scenarios described in Table 2

Interval	ESLC	D2	F1	F2
1B(=RSLC)	120	1	1	1
2B	138	0,8	1,2	1,2
3B	106	0,8	1	1,1
4B	127	0,8	1,2	1,1

3.1.4 Discussion of results from LCA

The results from the LCA are presented in Figure 2 and in Figure 3. When studying the results from the wood cladding one can see that the situation in industrial, polluted climate generally gives a higher score in the LCA than in rural inland climates. A study of this difference show the difference is about 40 % in favour of the rural inland climate (Average: IC: 2,2 mP/m^2 year, RIC: 1,4 mP/m^2 year). The walls facing south or north also give a difference in the durability of the cladding. A wall facing north gives an average environmental load of 2 mP/m^2 year, whereas a south facing wall results in a load of 2.5 mP/m^2 year (a difference of about 20 %).

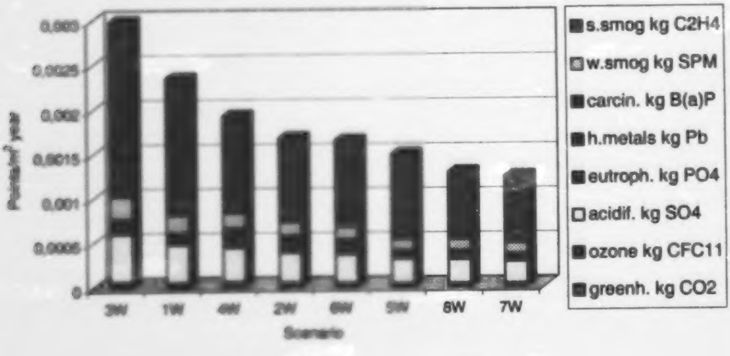


Fig. 2: LCA results from the use of wood cladding, calculated from LCA. The titles on the x-axis refer to the scenarios listed in Table 1.

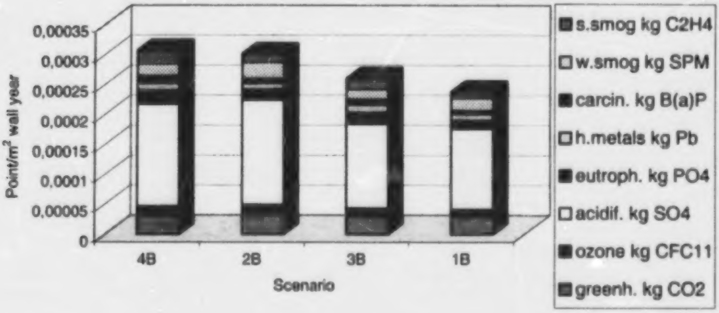


Fig. 3: LCA results from the use of brick veneer, calculated from LCA. The titles on the x-axis refer to the scenarios listed in Table 2.

The general impression is that longer painting intervals with a resulting shorter service life results in a lower environmental load than shorter intervals with longer SL. This is explained by the relatively high environmental impact of the painting (about 70 % of the load). Studying three different scenarios with almost identical ESLC, the environmental load is then approximately proportional to the painting intervals.

The analysis of the brick veneer results in difference of environmental load of 20 % between industrial and rural climate. The repairing of joints contributes to a relatively small part of the load. The intensity of the maintenance of the joint however affects the durability of the system and thereby, indirectly the environmental load. It is important to focus on the fact that the results are not definite results, but a consequence of the parameters and how they are varied.

An interesting scenario is also the case of wood cladding without painting. The problem will then be to determine which service life to use. Many would argue that the cladding are unfit for use beyond two years, because of the esthetical problems, however it should be noted that this represents a rather extreme situation. The technical service life however can in many cases be quite high in dry areas i.e. mountains. Table 5 shows LCA results for different scenarios of wood cladding with and without paint. In column one it is assumed that the esthetical service life will be 2 years for a wood cladding with no paint. In column three it is assumed that the technical service life of a wall without paint is 25 years in a south-facing wall in dry rural area.

Table 5: LCA of walls with no paint

	No paint, assumed esthetical SL of 2 years	Painted wall, 55 ESLC (Scenario 6W)	No paint, assumed technical SL of 25 years
Env. load	0,34	0,08	0,038

One should be careful drawing any strong conclusions from the analysis of the scenarios in this study. No variance is included in the databases or in the estimation of service life. However the main characteristics or trends from the study are useful.

For the scenarios with wood cladding, it is difficult to see any clear tendencies. It seams like the environmental load reduces with increasing service life, but the intensity depends upon the painting intervals. The best thing to do, from an environmental point of view, is to optimise the maintenance and service life. As stated before, walls in industrial areas with low painting intervals are very sensitive to estimated service life. There is however an overall large variation in environmental load for the different scenarios (about 60% from best to worst score).

Brick veneer show smaller variations in environmental load, due mainly to the relatively long durability of the material. The only distinction is that scenarios in polluted areas show a slightly higher load than scenarios in areas with no pollution.

One way to evaluate the importance of the service life data, and the correctness of these, is a comparison between the response to different weighting methods with the variation associated with service life prediction. The different methods give the worst and best score to the different scenarios. This shows that in LCA a major problem arises because of different weighting methods. Using Ecoindicator95/Europe, Ecopoint/Netherlands and EcopointCH (Prè Consultants 1997), the same scenario is rated with a differing environmental load of up to 23%.

4 Conclusions

- Service life prediction methods (SLP) and life cycle analysis (LCA) deal with some common problems. Most of the data in SLP are also needed in LCA.
- Information regarding the variation associated with the ELSC is crucial information in LCA. It is extremely important that the basis of both the stated SL and the performed LCA is clear, like e.g. maintenance type and interval. In this study it looks as if the maintenance is in fact the most important information.
- The life cycle analyses show that large environmental impact in manufacturing of a material can be justified if it is durable. Problems arise however if the technical service life is longer than the functional service life, and if such a durable material is replaced too soon.
- It is a problem that LCA techniques themselves give rise to large variation e.g. due to for example evaluation methods. LCA and SLP can be used together to optimise the service life and the resulting environmental load from different materials. Further development is needed for both systems.

5 References

Cole, R., J., Larsson, N. (1997) *GBC'98 Assessment manual*, Draft only

ENBRI, European Network of European Building Research Institutes. *Towards a framework for environmental assessment of building materials and components*, Draft version, Brussels May 1997

Hanssen, Ole Jørgen. (1997) *LCA-Theory and methodology*, NTNU

ISO. (1997) *Buildings - Service life planning - Part 1: General principles, Part 2: Service Life Prediction Methods*. ISO/CD 15686-1

ISO. (1984) *Performance standards in building: Principles for their preparation and factors to be considered*. ISO 6241: (1984)

Krogh, H. (1997) *Application of environmental data for calculation of environmental profiles of building elements*, Danish Building Research institute, Nordic Workshop, 3rd December

Larson, J. (1997) *Environmental valuation systems in the building sector - theory and practice*, Byggforskningsrådet, A6:1997 (in Swedish)

PRé Consultants, Database Manual SimaPro, Amersfoort, June 1997

Strand, S. M. (1996) *Survey of practical environmental criteria in the selection of material and structures, in planning, projecting and building*, Main Thesis, NTNU (In Norwegian)

PART FOURTEEN

LIFE CYCLE ANALYSIS AND SUSTAINABLE, DURABLE DESIGN

SUSTAINABLE DESIGN

188 ANALYSIS OF DISMANTLING VS. DEMOLITION — VISION OR REALITY

C. Boyle,[1] B.R. Kyle,[1] and A. Nesje[2]

[1]Public Works and Government Services Canada, Hull, QC, Canada;
[2]SINTEF, Trondheim, Norway

Abstract

Sustainability of buildings depends not only on the design for durability and flexibility but also upon the efficient use of resources for their creation. Unfortunately, most buildings constructed in Canada over the past 40 years were designed and built with a view to obsolescence. Many of the constituent components and basic building materials of these buildings may be capable of providing extended service life or be put to new usage. The challenge is to identify and harvest the durable components in an efficient and economical manner. The Federal Government of Canada is pursuing this goal through several projects. An example of the potential benefits of building dismantling practices was provided by a renovation of three floors of the Federal Building in Winnipeg, Manitoba, Canada. This paper describes the material diversion practices and examines the direct economic impact of the de-construction process upon this project. The paper further discusses the potential economic advantages to be realized through implementation of similar procedures in other locales.

Keywords: sustainability, dismantling, reuse, recycling, economic impact, de-construction

1 Introduction

Much of the world's population considers "use and dispose" to be standard operating mode and the construction industry has typically followed suit. There is considerable world -wide investigation into the reuse of certain industrial by-products to improve material or system performance, reduce costs and lessen environmental

Durability of Building Materials and Components 8 (Volume Three). *Edited by M.A. Lacasse and D.J. Vanier*. Published in 1999 by NRC Research Press, Ottawa ON K1A 0R6, Canada. ISBN 0-660-17742-0

impact. The recycling of construction materials is expanding very rapidly. Traditionally, the environmental benefits of using recycled materials are considered to be significantly greater and less tangible than the potential economic advantages. This is particularly true if material or component reuse implies a reduced technical performance. In countries where landfill or materials are scarce the economic advantages of recycling is considerably heightened and various technologies have evolved to reduce construction waste and minimise resource consumption (Tomosawa et al.1998; Pietersen et al. 1998). Even in countries without spatial and resource limitations there are increasing fees for waste disposal; haulage, tipping as well as direct taxes and an increasing desire to manage construction waste (Miller 1998; Wilson et al. 1998). With the reuse or redirection, comes the need to establish standards for the required material quality as well as the conditions governing application. Some efforts have been made to track the use and recoverability of building materials (John and Tinker 1998, Dal Zio et al. 1998) and there is extensive documentation on the performance implications of using supplementary cementious materials and recycled aggregates (Sagoe-Crentsil and Brown 1998; Molin 1998).

2 Government of Canada - Greening of Government initiatives

In response to international undertakings (United Nations 1988) the Federal Government of Canada launched "The Green Plan: A National Challenge" (Environment Canada 1990). This initiative has informed Canadians of the serious environmental problems facing the country and the world and the federal programs, laws, and other actions in place to address these issues.

The Bruntland Commission defined sustainable development as "development which meets the needs of the present generation without compromising the ability of future generations to meet their own needs" (United Nations 1988). The Green Plan (Environment Canada 1990) introduced this concept into government policies and activities and resulted in environmental goals for Canada. Among the general goals are a commitment to clean air, water and land; the sustainable use of renewable resources; and the proper management of our own house. Committing to lead the country, the Green Plan states:

> "The Government can lead by advocating; it can lead by legislating; and it can lead through its programs. But, first and foremost, the federal government can lead by **doing**."

2.1 Amendments to the Auditor Generals Act

In 1995, the federal government introduced the "Greening Government" policy (Environment Canada 1995a,1995b) that built on the Green Plan by more fully integrating the concept of sustainable development into the government's activities and ensure that all departments shared in achieving the environmental goals. Integral to Greening Government were amendments to the Auditor Generals Act (Canada Gazette 1995) creating the Commissioner of the Environment and Sustainable Development and required all departments to produce a Sustainable Development

Strategy (SDS) by December 31, 1997. Public Works and Government Services Canada (PWGSC) submitted its SDS on Earth Day in April 1997 (PWGSC 1997) (http://www.pwgsc.gc.ca/comm/sds).

2.2 PWGSC's Sustainable Development Strategy

There are eight major areas identified in PWGSC's SDS, and among these is the Waste Management Strategy. On this specific issue the general goal of the Green Plan has been transformed into the firm target of reducing the amount of material going to landfills by 50% relative to 1988 levels by the year 2000. Current PWGSC figures indicate that, department wide, 44% of material is recovered from the waste stream with even higher figures recorded for specific types of waste (i.e., office paper) or specific geographic areas (i.e., the National Capital Area). These results have largely been achieved without a directed effort towards the reduction of waste generated by construction, renovation or demolition (CRD) projects. While the Green Plan target will be met solely on the basis of office waste management, the application of waste reduction to construction projects will be necessary to meet further waste reduction targets and is the only responsible approach for the SDS.

PWGSC has begun to incorporate sustainable development in construction, renovation and demolition into specification practices and ordinary operating procedures (Dunbar and Kyle 1998). Under PWGSC's Environmental Management System (EMS) waste management is a priority; a program was developed to enhance techniques and tools to manage construction and demolition waste. Under the EMS, progress is monitored and reported so that continuous improvement can be made.

2.3 CRD waste management projects

Recent work that demonstrates PWGSC commitment and approach to CRD waste management includes projects from coast to coast. These projects include military base reductions and closures and office building renovations. From east to west, these projects are:

- Closure of the former US Navy Base at Argentia, Newfoundland.
- Planned renovation of the Dominion Building, Charlottetown, P.E.I
- Green Floors, Sir William Logan Building, Ottawa, Ontario.
- Renovation of the East Memorial Building, Ottawa, Ontario.
- Canadian Forces Base - Uplands, Ottawa, Ontario.
- Federal Building, Winnipeg, Manitoba. This project is the subject of the detailed review included in this paper.
- Two other buildings in Winnipeg.
- Canadian Forces Base - Esquimalt, British Columbia.

3 Case study - Winnipeg Federal Building

The Federal Building at 269 Main Street in Winnipeg Manitoba is a heritage building of steel and reinforced concrete frame construction with a partial exterior bearing wall of facing stone, built in 1938. The renovation project included the refurbishment of the entire 4th and 5th floors and part of the 3rd floor for a total of about 3,000 m2. The renovation did not involve any exterior work and is typical of the type of work the department expects to be concentrating on in the near future.

The areas renovated were of mixed office construction of various vintages. Portions of the areas were constructed of terracotta brick and plaster walls with marble base boards and other areas were built with more current metal stud walls and vinyl covered gypsum board panels. Mechanical and electrical services were provided above a hung ceiling of acoustic tiles. Heritage features included a number of solid wood panel doors from the original construction. The elevator lobbies, which were hidden behind later construction, were refurbished. The most notable feature of the renovation is the change from a floor plan with numerous enclosed offices to an open concept with adjustable workstations, few enclosed offices and small meeting rooms. The renovated areas were entirely gutted. The extent of the typical floor renovation is illustrated in Figure 1.

3.1 Special considerations

Besides the examination of waste diversion and de-construction techniques, the objectives of this study included a comparison of a number of waste management approaches and to heighten awareness of the concept to PWGSC's staff as well as the professional and contracting communities. Through the experience in the cases discussed in Section 2.3, PWGSC has demonstrated that these concepts take hold most effectively when they are demonstrated within the local community. Local conditions have a critical influence on the effectiveness of the approach, as do the individuals involved. In order for such a different tact to gain appreciation and acceptance, it must be seen as workable within the local conditions.

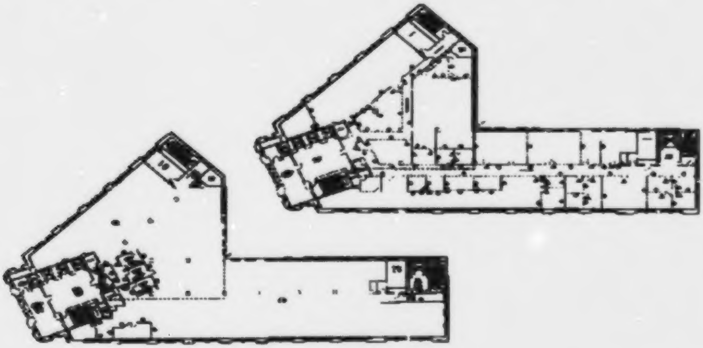


Fig. 1: Architect's plan of 4th floor - demolition (upper right) and renovations (lower left)

It was also considered important that the experience gained on other projects is extended to all the regions of the department; relevant experiences must be shared.

Heightening awareness of dismantling possibilities implies not only an adjustment on the part of the federal government but also on the part of the design consultants and construction contractors. The greatest opportunities lie with renovation projects. The design team(s) should be aware of the opportunities to recover and reuse material that will be generated by the removal of the existing facilities. If feasible and upon meeting performance requirements, reused material should be incorporated into the new facilities. When designing the new facilities, the design team should also be aware that at some point in the future another renovation of the space is likely. Therefore, the space should be designed with the potential to be dismantled, with the highest proportion possible of the materials available for reuse with minimal damage.

The construction contracting companies are also going to have to take a new approach for improved waste management to work. These companies must see the benefits and value of materials recovery. This means that the owner/investor, and their representatives, the architects and engineers, will have to share in the risks as well as the benefits. Contractors will have to be given sufficient information to make reasonable bids or given the time and opportunity to gather the information themselves. They must also be allowed the time necessary to carry out the dismantling of the space in question and to train their staff adequately in the principles and techniques involved.

3.2 Material waste audit procedures

The waste management consultant supplied a comprehensive and effective waste audit and management system, used for the Winnipeg Federal Building renovation. This system is a comprehensive and effective waste management system. It consists of audits of the construction, renovation or demolition site, an evaluation of the material recovery options through reuse or recycling, as well as a strategy or work plan on how to achieve the most effective and efficient result.

The three principal stages of the implemented CRD waste management system, their components and interactions are depicted in Figure 2.

The primary environmental benefit comes from the diversion of significant quantities of valuable resources away from landfills; thereby diminishing the need for new landfills and all the environmental issues that are associated with them. These environmental issues include the loss of valuable land, generally close to urban centres and the reduction of the associated toxic and non-toxic waste products. Second, the resources represented by the construction materials are not lost to potential further use. The objective here is to achieve as high a percentage as possible of materials diverted. The best possible end point is realized when the percent reused approaches the percent diverted, as it is always preferable to reuse a product rather than recycling it.

The results of the waste management Work Plan, in the form of materials tracking, are summarized in Table 1.

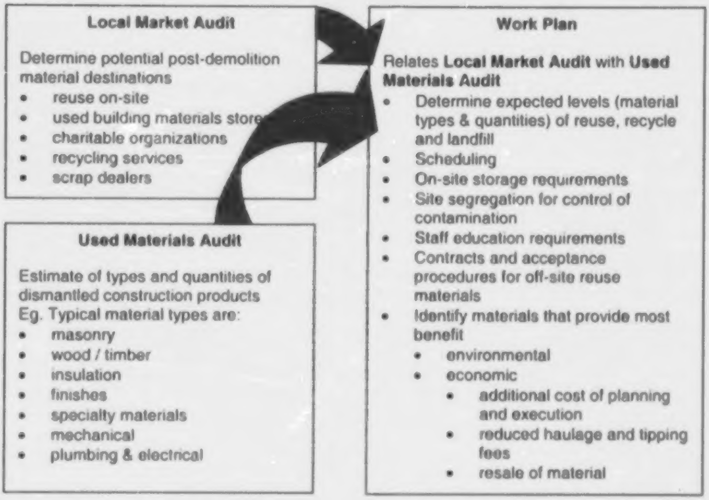

Local Market Audit
Determine potential post-demolition material destinations
reuse on-site
used building materials stor
charitable organizations
recycling services
scrap dealers
Used Materials Audit
Estimate of types and quantities of dismantled construction products
Eg. Typical material types are:
masonry
wood / timber
insulation
finishes
specialty materials
mechanical
plumbing & electrical
Work Plan
Relates **Local Market Audit** with **Used Materials Audit**
Determine expected levels (material types & quantities) of reuse, recycle and landfill
Scheduling
On-site storage requirements
Site segregation for control of contamination
Staff education requirements
Contracts and acceptance procedures for off-site reuse materials
Identify materials that provide most benefit
environmental
economic
additional cost of planning and execution
reduced haulage and tipping fees
resale of material

Fig. 2: Principal stages of the CRD waste management system

Table 1: Materials tracking summary

Material Description	% of Total Weight	% Landfilled	% Reused	% Recycled
Masonry	48.17	0.00	-	100.00
Wood	0.33	14.97	79.68	5.35
Doors & Windows	2.47	0.00	11.79	88.21
Finishes	41.21	8.09	35.36	56.55
Specialties	0.07	0.00	0.00	100.00
Mechanical	3.26	0.00	68.05	31.95
Electrical	4.49	3.78	59.66	36.56
Totals	100.00	3.55	20.02	76.43

3.3 Special procedural considerations/requirements

The waste management system has different requirements from the more common demolish, haul and dump approach. The planning and scheduling requirements are considerably greater. For projects with tight time lines, a full waste management program is almost impossible to complete because of this increased planning requirement. Even in projects with a less stringent schedule, the waste management portion must be carefully examined to ensure it does not adversely affect the project's critical path. There is little historical experience on which to base an estimate of the scheduling adjustments necessary. Even on this relatively small project, conflicts between demolition and renovation led to some materials being moved and stockpiled three times before they were reused. This increases overall project costs. It is however almost impossible to predict by how much, because of the unknowns involved in the interaction between demolish/dismantle and reconstruct tasks.

The contractor selection criteria will also be more stringent and the demolition contract may well be separate from the renovation construction contract. The contractor carrying out the de-construction must at least demonstrate an appreciation for the objectives of the waste audit and work plan and an ability to implement it. Preferably the contractor will have experience with a full management plan but this is not common at the moment.

Since the materials that are being removed are now considered to be of value, security issues are more important. This is significant in relation to ensuring that the materials are not damaged during their removal or storage as opposed to protecting them from theft. Carelessness on the job site can easily result in destruction or diminished value of these materials. Another area of possible loss of value is the contamination of reusable or recyclable material at the waste bins. A material that has value as a single recyclable product immediately looses that value with any degree of contamination. Consequently, one of the main goals of worker education is to emphasize that the separate bins for separate material types must be respected. Ensuring that the bins are clearly marked greatly aids this goal. Care must also be taken to ensure that the bins are secure and that incidental contamination does not take place by unauthorized dumping by the general public.

Finally, to ensure that the value of the dismantling approach can be demonstrated, a system of tracking the destination of the various products derived from the process need to be established. For materials reused on-site this means estimating the avoided costs of disposal (haulage and tipping fees) as well as the value of the materials that did not have to be purchased. If materials are sold for reuse, this revenue should be added instead of the avoided cost of purchased material. For recycled materials again this value includes the avoided disposal costs, plus any revenue realized, less haulage charges, if any. The disposal costs of material that is actually landfilled will have to be added. These expenses and revenues can be tracked through retaining copies of sales receipts, transport weigh bills, and tipping fee receipts. Unfortunately, this is not standard practice during demolition work and requires diligence during this phase. Under tight time lines that are already being stretched during demolition, these items are frequently overlooked and the information necessary to analyze the cost effectiveness of the dismantling process relative to standard practice is lost. This was partially the case in the Winnipeg Federal Building case; some information was available but not enough to make a valid comparison. The project manager estimated that the overall costs of the dismantling approach resulted in 10 to 15% higher costs.

3.4 Experience gained

This renovation project has provided some useful lessons relative to successful de-construction. This section summarizes them briefly.

1. Planning must start early and include all those involved in the project. The waste management approach and required skills differ from the current practice;

additional information and education is required.

2. Dismantling, or de-construction, takes a significantly longer time than demolition and must be accounted for in a revised project schedule.
3. Economic data must be collected in as consistent a manner as possible. In order to obtain a definitive statement about the relative economic costs and benefits of waste management the whole economic picture must be seen. Some suggested reasons for the inability to collect sound financial data for this project are:
    - the "newness" of the system to those implementing it;
    - a proprietorial attitude of contractors to cost data; and
    - inadequate resources to effectively supervise the work and ensure that the tracking is taking place.
4. Inconsistency on policy issues and lack of communication between and within various levels of government contributes to the difficulties of solid waste management. Low tipping fees, acceptance of all types of non-hazardous waste (regardless of their environmental impacts) and restrictive policies on site management or the disposal of materials with economic value (i.e., forbidding on-site sale of recovered materials) act as disincentives.
5. The benefits of non-hazardous solid waste management of CRD projects are real. Reduced hauling and tipping fees and possibly revenues from the sale of materials are amongst the firm benefits. There are the less tangible benefits, usually relate to environmental protection.
6. Transportation is a controlling issue in the solid waste management of construction materials. Because recovered materials, whether for reuse or recycle, command only a fraction of the value of new materials, generally less than 20%, they cannot tolerate transport for great distances. The reuse and recycling of construction materials is highly sensitive to local conditions and the development of the local infrastructure.

4 Assessment of the existing infrastructure capabilities in Winnipeg

The issue of local infrastructure is of such importance that it formed a basic element of a recent Canada wide study of solid waste management (CCA 1998). The study, a survey of obstacles and opportunities in seven urban areas, including Winnipeg, focused on several issues but clearly identified local infrastructure as a controlling feature.

Winnipeg's infrastructure was found to be "limited". There are only three "retail" outlets dealing in used construction materials, one general contractor who incorporates material salvaging in projects and uses this as a source of product inventory. Some contractors do limited recycling of concrete and asphalt.

This limited infrastructure is partially a result of an abundance of landfill capacity, estimated at more than a hundred years with tipping fees at $40.00/ton and a relatively static population base.

The Project Manager of the Winnipeg project was unable to negotiate the sale of any of the materials removed on the project. For this reason much of the reusable material was donated to a local charitable organization, passed to employees working in the building and used to assist in restorations following the destructive Red River flooding in the spring of 1997. The contractor also re-deployed several of the door-and-sidelight assemblies on another project.

5 Projected economic impact in other locales

The local circumstances are a fundamental aspect of the relative success of a waste management project and it is worthwhile to examine this aspect in the context of other locales, at least in a hypothetical sense. A brief comparison for this Winnipeg project and what might be expected in five other Canadian cities, as reflected in data from the CCA study (CCA 1998), is summarized in Table 2.

Table 2: CRD waste management costs and issues for six cities

City	Regulatory System	Labour ($ / hr)	Transport ($ / tonne)	Tipping Fees ($ / tonne)	Landfill Capacity (years)	Used Building Materials & Recycle Facilities
Vancouver	Landfill Restrictions	14	125	> 40	50 plus	Well Developed
Calgary	Absent	10	20	< 30	Not available	Limited to Adequate
Winnipeg	Absent	17	80	40	100 plus	Limited
Hamilton	3Rs Regulations	16	35	> 40	50 plus	Well Developed
Quebec	Absent	17	60	< 20	~50	Highly Limited
Halifax	Regional Solid Waste Management	10	50	30 - 100	Not available	Moderate & Developing

A precise analysis of the economic factors affecting CRD non-hazardous solid waste management in the selected cities requires more accurate data than was available for this study. However, a general impression of the relative economic effectiveness can be determined using information that reflects the local circumstances, as summarized in Table 2, and cost estimates for the materials removed from the renovated floors of the Winnipeg Federal Building. The analysis must also depend on an assumption that where infrastructure is well developed all the material removed for disposal by resale or recycling will, in fact, be disposed of in this manner. A further assumption is that materials disposed of by sale for reuse will generate revenue at 15% of their estimated list cost and those disposed of by recycling will generate revenue of 5% of their estimated list cost. Given these conditions and assumptions, the relative economic effect of implementing a waste management program versus a more traditional demolition of office interior space as represented by renovation of 3rd, 4th & 5th Floors of the Winnipeg Federal Building can be approximated. The first comparison of interest is a cost estimate of a "standard" demolition of the subject floors in each of the selected cities. This comparison is based on the assumption that all materials that are removed are treated as general waste and transported to a landfill for disposal. These results are summarized below in Table 3.

Table 3: Estimated project costs of "Standard" demolition for six cities

City	Labour ($K)	Trans. + Tip. ($K)	Scrap Revenue ($K)	Total ($K)
Vancouver	13.9	94.3	-1.8	106.4
Calgary	9.9	28.6	-1.7	36.8
Winnipeg	16.8	68.6	-1.6	83.8
Hamilton	15.8	42.9	-2.3	56.4
Quebec	16.8	45.7	-2.3	60.2
Halifax	9.9	65.7	-1.6	74.0

The "Labour" represents an estimated 168 person-days (8 hours/day) required to complete the demolition, "Trans. + Tip." represents transportation costs and tipping fees, "Scrap Revenue" is the estimate of revenue from the sale of scrap metals and "Total" is the net total cost.

A variation between cities is obvious, from a low of $37k in Calgary to $106k in Vancouver. The reason for this variation is clearly related to transportation costs and tipping fees at landfills. The variation in labour costs is less than $9k and over all is a relatively small portion of the costs and in the case of scrap revenue; the difference is only $0.7k and is an even smaller portion of costs.

When the concept of dismantling or de-construction is applied to this project and then extrapolated to the six cities of this study, the contrasts become even more dramatic. Projects that take place in urban areas that have well-established infrastructures to support 3Rs (reduce, reuse and recycle) dismantling can benefit to an even greater degree. This has been summarized in Table 4.

Table 4: Estimated project revenues and costs of 3Rs de-construction for six cities

City	Value of Material ($K)			Trans. + Tip. Fees ($K)	Add. Mgmt. + Labour ($K)	Net ($K)
	Reuse On-site	Reuse	Recycled			
Vancouver	70.5	24.2	19.1	-1.4	-12.8	99.7
Calgary	70.5	0.0	13.4	-2.8	-12.8	68.4
Winnipeg	70.5	14.6	20.7	-3.0	-12.8	90.1
Hamilton	70.5	22.8	18.7	-1.6	-12.8	97.6
Quebec	70.5	0.0	13.6	-4.1	-12.8	67.2
Halifax	70.5	25.3	14.2	-2.8	-12.8	94.5

Merging Tables 3 and 4 combines the cost elements of the "Standard" labour, additional management and labour, the avoided transportation and tipping fees and the required transportation and tipping fees for the approximately 4% residual solid waste. The result gives a general impression of the net benefit of proceeding on a 3Rs Waste Management dismantling approach as opposed to the "Standard" demolition approach for this case study project in these same six cities. The net benefit for each location is presented in Table 5.

Table 5: Project net benefit of 3Rs waste management for six cities

City	Value of Material ($K)			Avoided Trans. + Tip. Fees	Trans. + Tip. Fees	"Standard Labour"	Add. Mgmt. + Labour	Net
	Reuse On-site	Reuse	Recycled	($K)	($K)	($K)	($K)	($K)
Vancouver	70.5	24.2	19.1	92.9	-1.4	-13.9	-12.8	178.6
Calgary	70.5	0.0	13.4	25.8	-2.8	-9.9	-12.8	84.2
Winnipeg	70.5	14.6	20.7	65.5	-3.0	-16.8	-12.8	138.7
Hamilton	70.5	22.8	18.7	41.3	-1.6	-15.8	-12.8	123.1
Quebec	70.5	0.0	13.6	41.6	-4.1	-16.8	-12.8	92.0
Halifax	70.5	25.3	14.2	63.0	-2.8	-9.9	-12.8	147.5

6 Conclusions

The de-construction project of the Federal Building in Winnipeg was a success from an environmental aspect and also in consideration of the economic benefits.

Projections to other cities indicate that the proposed de-construction approach will be of economic advantage in all examined locales despite there being considerable variation in the magnitude of that benefit.

7 Recommendations

For renovation projects, of a comparable scope to that examined in this study, de-construction should be considered a viable alternative to the traditional demolition and dispose phase of project execution.

Several suggested improvements to the implemented system should be included in the execution of future de-construction projects and particular care should be taken to record the economic performance factors.

8 Acknowledgements

The authors of this paper gratefully acknowledge the involvement and contribution to the case study project from *by dEsign Ltd.*, the waste management consultant, and by Mr. Jim Plamquist, the Project Manager of the Winnipeg case study de-construction.

9 References

Canada Gazette, Part I (1995) *An Act respecting the office of the Auditor General of Canada and sustainable development monitoring and reporting, c. 43, s.1.* , Ottawa, Canada.

Canadian Construction Association (CCA)(1998) *Construction and Demolition Waste Survey Report*. May, Internal Report, prepared by Resource Integration Systems Ltd., Ottawa, Canada

Dal Zio, E., Vergine, F. and Paparella, R. (1998) "Recoverability" of building elements in recovery intervention. *Proceedings of the CIB World Congress 1998*, June, Gävle, Sweden.

Dunbar, T. and Kyle, B.R. (1998) Greening of Canada's National Master Specification. *8th Durable Building Materials Conference*, May 30-June3, Vancouver, Canada.

Environment Canada (1990) *Canada's Green Plan for a Healthy Environment*. Minister of Supply and Services, Cat. No.: En21-94/1990E, Ottawa, Canada.

Environment Canada (1995a) *Directions on Greening Government Operations*. Minister of Supply and Services, Cat. No.: En 40-497/1-1995E, Ottawa, Canada.

Environment Canada (1995b) *A Guide to Green Government*. Minister of Supply and Services Cat. No.: En21-136/1995E, Ottawa, Canada.

John, V.M. and Tinker, J.A. (1998) Recycling waste as building materials: an Internet database. *Proceedings of the CIB World Congress 1998*, June, Gävle, Sweden.

Miller, A.J. (1998) Energy implications of the transportation of building materials. *Proceedings of the CIB World Congress 1998*, June, Gävle, Sweden.

Molin, C. (1998) Recycling of concrete in Sweden. *Proceedings of the CIB World Congress 1998*, June, Gävle, Sweden.

Pietersen, H.S., Fraay, A.L.A. and Hendricks, C.F. (1998) Application of recycled aggregates in concrete. *CANMET/ACI International Symposium on Sustainable Development of the Cement and Concrete Industry*, October, Ottawa, Canada.

Public Works and Government Services Canada (PWGSC) (1997) *Sustainable Development Strategy*, April, Real Property Services Branch, P35-99/1997, Ottawa, Canada.

Sagoe-Crentsil, K. and Brown, T. (1998) Performance requirements of building products derived from construction and demolition waste. *Proceedings of the CIB World Congress 1998*, June, Gävle, Sweden.

Wilson, O.D., Skitmore, R.M. and Seydel, A. (1998) Waste management in the construction industry. *Proceedings of the CIB World Congress 1998*, June, Gävle, Sweden.

Tomosawa, F., Noguchi, T. and Tamura, M. (1998) Towards zero-emissions in concrete industry: advanced technologies for concrete recycling. *Proceedings of the CANMET/ACI International Symposium on Sustainable Development of the Cement and Concrete Industry*, October, pp. 147-160, Ottawa, Canada.

United Nations' (1988) *Our Common Future*. World Commission on Environment and Development (UNWCED), Oxford University Press, Toronto, Canada.

189 EVALUATING THE SUSTAINABILITY OF ALTERNATIVE WINDOW AND PROPRIETARY GLAZING SYSTEMS

A.W. Brown,[1] S.J. Allwinkle,[2] and G.F. Weir[3]

[1]Heriot Watt University, [2]Napier University, and [3]Blyth & Blyth,
Edinburgh, UK

Abstract

The sustainable design of buildings and building components represents a complex problem and requires the examination of many variables across a number of disciplines. For contemporary building assets to be truly sustainable, they must be capable of being supplied at a positive rate whilst ensuring that resource stocks are not compromised. Moreover, their delivery and subsequent operation must not compromise the future quality of the environment. Such requirements impact all area's of future building design and delivery. Windows and proprietary glazing systems are principal components in the external envelope of contemporary office buildings. As such, an evaluation of the sustainability of window systems is considered to be of importance in gaining an improved understanding of the sustainable design of buildings as complete systems. The evaluation of windows and proprietary glazing systems must be undertaken on two fronts. First, it is necessary to undertake a detailed Life Cycle Assessment of window systems in order to identify optimum approaches for given circumstances. Building designers can subsequently introduce these optimum systems, given the known performance characteristics of other building elements, having confidence that the environmental impact that is associated with the specified windows is minimised having taken due consideration of the functional performance characteristics that are required. Second, it is necessary to understand how important optimising the window system is in relation to improving the overall sustainability of a complete building as it functions as a total system. This paper presents work undertaken to produce a detailed Life Cycle Assessment of window systems in offices and commercial buildings. Subsequently, a causal path model is proposed to understand the relative importance of window systems in determining the overall environmental performance of buildings in relation to other key building elements and sub- systems.

Keywords: Sustainability, Life Cycle Assessment, Window systems, Causal Path

Durability of Building Materials and Components 8 (Volume Three). *Edited by M.A. Lacasse and D.J. Vanier*. Published in 1999 by NRC Research Press, Ottawa ON K1A 0R6, Canada. ISBN 0-660-17742-0

1 General sustainability and evaluation issues

There is now a general consensus that buildings and the components that are used in the assembly of buildings must be sustainable. There is, however, much debate and little consensus concerning what does and what does not represent sustainability. The interpretations placed on sustainability vary depending upon the scale of the product that is under scrutiny. The sustainability of an individual building component is not considered in the same way as pure sustainable economic development. Nevertheless, it seems clear that the sustainability of buildings, and therefore by implication, the sustainability of building components, requires some focus upon minimising the energy and resource consumption that is associated with both their production and use. Furthermore, attention must be paid to the levels of pollution that are associated with these activities. Sustainability, in the context of buildings and construction activity, has as its primary aim, the reduction of the environmental impacts that are associated with development. There are a number of approaches that are appropriate in relation to quantifying the magnitude of environmental impacts of products. However, in recent years the use of Life Cycle Assessment (LCA) for this purpose has risen to prominence (Field et al. 1994). Indeed, LCA's are considered as necessary when sustainability is promoted as a primary objective (Lawson 1995). LCA's involve the systematic analysis of products and services using a complex input- output model that captures data which are associated with the entire life cycle of those products or services. Thus, energy content in production, use and disposal is investigated together with assessing the extent of detrimental pollutants that are produced in connection with each of these three stages. The approach is robust and rigorous in application to a given product or service provided that the product or service in question is not greatly complex since sensible boundaries must be defined in relation to data acquisition. Obtaining the data necessary to undertake a robust LCA for a particular window system, for example, whilst a complex task, is substantially different from obtaining the data required to perform a valid LCA for a complete building, where hundreds of individual components and products interact in a complex manner to function as a total system. It is argued that identifying an optimum product using LCA methods and subsequently introducing that product into the system of a complete building does not necessarily mean that the sustainability of that building will improve. Therefore, it is suggested that the analyses produced by LCA's undertaken for individual building products and components must be extended in order to understand the relationship between those products and the sustainability of buildings as total systems.

2 The importance of windows and proprietary glazing in sustainable building design

In recent years improved performance has been demanded from the external building envelope in relation to thermal control and in relation to the admittance of daylight (Weir 1998). The driver for this demand is fundamentally energy related and has its origins in the fuel crisis of 1973.

Of course, increasing emphasis has continued to be placed upon the need to conserve world resources and this is the key in sustainability considerations. The external building envelope is clearly of central importance in the energy consumption of buildings since it acts as the primary interchange between external and internal environments. In contemporary office or commercial buildings, the window or proprietary glazing system is a major part of that external building envelope. Therefore, given the importance of the external envelope in relation to the overall energy consumption of buildings and given the importance of energy consumption in connection with sustainable building design, it is clear that on an *a priori* basis, the window or proprietary glazing system is of much importance in the sustainable design of buildings as complete systems.

The energy consumed by contemporary office buildings over a complete life cycle is influenced by a number of important variables apart from the external envelope. These include the location of the building, its orientation, the thermal mass inherent within the building structure, the level of services that are incorporated, and the extent to which high technology energy solutions are incorporated within the building[1]. However, the importance of the external building envelope and in particular, the window, is considered to be significant for the following reasons. First, glazed area's typically account for a significant proportion of the external envelope of contemporary office and commercial buildings. Second, glazed area's are the principal vehicle for the introduction of natural light to the interior of buildings. This means that the energy consumption related to the provision of light within office space can be influenced by the glazed areas in a significant manner. There are, of course, a number of methods available to actively interfere with the introduction of natural daylight into interior building spaces, either to improve this, or to reduce it in connection with glare. Components that are used in this manner are not themselves integral to the window or to the glazing system. Nevertheless, the window still acts as the conduit for the introduction of light, even if some other active manipulation system is evident. Third, the window is significant in terms of its substantial contribution to the overall thermal control properties of the external envelope, both in relation to the admittance of solar energy (which again can be assisted by technologies that are not integral to the window or glazing system) and in relation to the heat loss through the external fabric.

Clearly, the investigation of windows and proprietary glazing systems is of importance in determining sustainable design methods for buildings as total systems. Investigation is necessary on two fronts. First, an LCA undertaken in relation to alternative available window and glazing systems will provide an important step in identifying an optimum approach to the provision of glazed area's in the external envelope of contemporary office and commercial buildings.

Second, and arguably of greater importance, is the need to investigate the impact that window systems have upon the overall sustainability of a building when that building is considered as a complete system rather than simply as the sum of its elements.

Understanding how important windows and glazing systems are in terms of the contribution that they can make to a reduction of the total environmental load imposed by a building is argued to be of much importance in securing an understanding of how the environmental performance of a building as a whole may be optimised.

---

[1] Technologies that may be included to reduce or optimise energy consumption of buildings in use include; Natural Ventilation, Chilled Ceilings and Floors, Brise soleil, Light shelves, and Photovoltaic (PV) cells. Some of these interact directly with the window systems while some do not.

3 Environmental analysis and life cycle assessment

3.1 The life cycle assessment method

Previously, the evaluation of products in relation to the impact that they have upon the environment has generally examined four main areas; namely, the energy use involved in their production, the air pollution involved, the water pollution and finally, the level of solid waste involved. Contemporary studies continue to examine these areas, however, the scope of environmental analyses has been extended. At the present time an appropriate assessment may be considered to comprise an analysis of the environmental effects which are related to; resource consumption; pollution (waste, emissions and discharges); and, social and welfare effects. Conventionally, *Life Cycle Assessments* (LCA) are used in order to determine the environmental load of particular products or systems. When one or more products that have the same functional purpose are investigated using conventional Life Cycle Assessment methods, the optimal product can be identified as that having the least environmental load over its entire life cycle whilst still adequately satisfying the identified functional purpose. LCA has been defined as a systematic inventory and a comprehensive assessment of the environmental effects (ie. resource consumption, Pollution and Welfare effects) of two or more alternative activities involving a defined product in a defined space and time including all steps and associated products involved throughout their life cycles (Little and Pederson 1993). LCA are now made on the basis of a standard that is generally accepted; an inventory is made of all the interference's with the environment that are caused by or that are associated with a particular product or system. These are classified in order of their perceived relative importance (Hammans 1995). A Life Cycle Assessment is therefore a comparative evaluation of *all* aspects of particular products, which must adequately meet a specific function, in terms of how they relate to the environment. Furthermore, it is an analysis of the environmental effects that are associated with all of the complementary products and processes which are introduced to a particular system (such as a building) by the selection of the primary product (such as a type of window).

The process of undertaking an environmental Life Cycle Assessment is highly data intensive and rigorous. The products in question, the associated performance specifications and the functions require to be analysed to ensure that the investigator is undertaking a valid study. The Life Cycle Assessment process is not so much concerned with the comparison of particular products themselves but is rather concerned with the function that must be realised.

The products are subsequently analysed in an attempt to determine which most appropriately (in terms of environmental effects) delivers the identified functions. In typical Life Cycle Assessments, the function may be quantified in terms of *the functional unit of product*. Thereafter (in theory at least), the products being assessed in a given LCA should deliver 'equal amounts' of the identified functional unit in order that a valid comparison is realised. The environmental effects are then assessed in relation to the delivery of that function.

3.2 Life cycle assessment of window systems

A full Life Cycle Assessment of alternative window systems has been undertaken; 24 different window constructions were assessed and the results have been previously published (Weir 1998; Weir and Muneer 1998). The functional unit of product in this case was defined as a Joule per window (J/w). To be meaningful the LCA undertaken considered three principal design criteria that must be delivered in relation to the basic functional requirements of windows. The criteria were; thermal control, sound attenuation and daylighting. With regard to thermal control, the assessment took the form of an energy consumption analysis and a comparison of the convective heat input that is required to maintain thermal comfort conditions. The thermal analysis allowed for the contribution made by other components incorporated within the external envelope and the results of the analysis depend in part upon the level of specification which is evident for each of these. The various window constructions are also analysed in connection with their sound attenuation properties. Finally, a visual analysis in relation to the provision of natural daylighting provides a methodical approach to assessing the energy consumed by artificial lighting within the building interior, given that a desired lighting level must be maintained for efficient task performance.

The window and glazing systems included in the assessment comprised four single glazed options in addition to various double and triple glazed constructions, adopting either single or double applications of low emissivity coatings. Four options for cavity infill gases were incorporated in the assessment of double and triple glazing systems; these were, Air, Argon, Krypton and Xenon.

An optimisation model was developed which links the thermal, acoustic and visual performance of the 24 differing window and glazing constructions. The outputs generated from this model may be used to evaluate the optimum window design in terms of energy consumption and global environmental impact. Optimisation of energy consumption incorporated analyses of embodied energy, thermal energy requirements and artificial lighting energy demands over the life cycle of a window; this was considered to be a period of 20 years. Global environmental impact optimisation follows a similar rationale, however, evaluation is based on energy generation and greenhouse gas production (in particular CO_2, SO_2 and NO_x).

A flowchart for optimisation was developed. This guides building designers towards a window and glazing system which offers sufficient sound attenuation, thermal and visual performance whilst minimising the overall environmental impact over a 20 year period.

This rigorous LCA allows the designer to select an optimal window system from a functional performance and from a sustainability point of view, given a particular cladding approach or a known specification in relation to the remaining components that are incorporated within the external building envelope.

The boundaries of this LCA were set at the level of the performance of the windows themselves, as components within the external fabric. Therefore, the performance of the window was considered in a passive sense and the optimisation does not allow for active intervention in the performance of the window function such as may be realised by the introduction of technologies such as brise soleil, light shelves, reflective mirrors, louvres and such like.

Nevertheless, the model provides a useful tool in attempting to optimise the environmental performance of conventionally designed office buildings as far as the passive influence of the window and glazing systems upon the overall environmental performance of buildings is presently understood.

However, the precise nature of this influence is not well quantified. The situation is further complicated when so called 'environmental buildings' are considered. Such buildings use active technologies to reduce overall energy requirements and thus to reduce the overall environmental load that they impose. Buildings which are naturally ventilated, with good thermal mass properties, using technologies such as light shelves, louvres, brise soleil and photovoltaic (PV) cells, consume minimal amounts of energy over their operational life cycles. In such cases the rationale for the optimisation of building components in relation to LCA results and environmental performance criteria, is substantially altered, as the relative importance of different environmental assessment classes, such as embodied energy, become materially changed. This means that conventional LCA's carried out in relation to individual products and components are not necessarily meaningful when the building is considered to function as an overall system.

Windows and glazing systems are considered to be of much importance in the production of buildings that are sustainable. Understanding *how* important they are in relation to the achievement of what may be termed true sustainability in the context of a complete building system, which fully exploits the types of technologies that have been briefly discussed, is argued to be of much importance.

Clearly, *a priori* reasoning would suggest that the window system and glazing approach are important, in a statistically significant manner, to the overall improvement of building sustainability (where buildings are understood to behave as complete systems). However, this presumption requires to be tested in a rigorous and sound manner.

4 The need for a further assessment

One approach to making an assessment of the importance of the window system in reducing the total environmental load imposed by buildings would be to undertake Life Cycle Assessments for complete buildings. The importance of the window system in contributing towards the overall environmental performance of a building could be subsequently identified, in theory at least. It is argued that there are, however, considerable methodological difficulties in undertaking LCA's for complete building systems. The product and sub- product chains that are present in even the most simple contemporary building make the acquisition of data of sufficient veracity over the eleven accepted environmental classes that are included in the standard method developed by CML (Centre for the Environment, Leiden, the Netherlands) difficult. Hence, the completion of a valid and meaningful total building LCA is an intractable task. Nevertheless, research effort is presently being focussed on developing approaches to LCA for complete office buildings which are scientifically valid, and which overcome these methodological difficulties (Hendriks 1998). Such methods are unavailable at the present time. Regardless, the appropriateness of applying LCA methodologies to the research problem that has been outlined above, is considered to be questionable.

What is required is a method which can relate measures of particular building materials or component systems to the overall sustainability of complete building systems. Quantifying the latter need not necessarily be approached with an LCA mind- set. As a starting point, it is suggested that the level of energy consumption over the operational life of a building may be used as a proxy to estimate its overall imposed environmental load. Such a measure would, of course, be incomplete from a purist standpoint, however, it is considered to be appropriate. The overall environmental impact is substantially influenced by energy production since this has obvious effects on primary resource consumption, pollution, and upon social and biophysical factors. Clearly, energy production and consumption is not the only determinant on the overall damage that is inflicted in relation to these areas. Nevertheless, consensus suggests that the contribution of energy production and use to the final detrimental affects on these factors, is significant. Therefore, although there are limitations, it is argued that an assessment of the level of energy used over the lifespan of a building is a suitable proxy to estimate the total environmental load imposed by a building. This being the case, a measure, quantified in GJ/m^2/year, may be considered to be an appropriate approximation of the environmental burden associated with a given office building. A method capable of relating window specifications to this overall measure is required. The method must be able to quantify the strength of the causal relationship between the window systems and the overall environmental result. Furthermore, it should be able to measure the strength of the influence of the window system upon overall environmental performance *relative* to the strengths of influences that are present between other building sub- systems and components and the overall environmental result. Such an evaluation will permit an improved understanding of how important window systems are in relation to other low energy technologies and strategies that are presently implemented in attempts to make buildings more sustainable. It is proposed that path analysis represents a suitable method for the research objective as defined above.

5 The causal path method

The causal path method provides a robust analytical framework within which the strength of influence between interrelated variables can be measured and understood. It provides for the quantitative investigation of postulated causal influences between a set of interdependent variables (Little 1979; SWCS 1990). The method allows the formulation of intuitive ideas concerning which of the causal influences are significant. A path model is typically specified as a system of simultaneous regression equations which are assumed to be linear, additive and recursive (Boyle 1970). Path coefficients, the standardised partial regression coefficients, are calculated from the regression equations. These provide an indication of the relative importance of a given explanatory variable upon the response variables. The coefficient is usually described in the form, pi,j, where the subscript, j, refers to the response variable and, i, refers to the regressor whose direct effect upon the response is measured. Normally, the path coefficient, Pi,j, explains the proportion of the standard deviation observed in the response variable, j, for which the regressor variable, i, is directly responsible. The residual path coefficient measures the proportion of the standard deviation of j which is explained by unmeasured extraneous variables.

Prerequisite to the construction of any path diagram is the assumption that the variables can be placed in a causal ordering. This cannot be decided by empirical analysis of data; it must be determined from prior theoretical knowledge. The *a priori* structure provides the framework for the statistical analysis of data and also for the interpretation of the results. The fundamental task in applying the path analysis method is the construction of a path diagram which reflects as closely as possible the true situation.

6 Defining a causal path model appropriate to the present study

The purpose of the proposed evaluation is to determine how significant the influence of the window system is in determining the overall environmental load of a building over its useable life cycle. Subsequently, it is of importance to understand whether or not changing the specification of window systems will reduce the overall environmental load of a complete building in a statistically significant manner, giving due consideration to other energy technologies that may also be present in a given building. Therefore, the rationale of the path diagram and the path model to achieve this evaluation is relatively straightforward. The window systems, together with a series of other building sub-systems must be seen as the causal influences that contribute the total environmental load of the building. The purpose is to measure the relative strength of the window systems in relation to other subsystems in contributing to this environmental result. Put simply, the environmental result (GJ/m^2/year) may be termed the ultimate dependent variable; the building sub-systems and the interactions between them are the regressor or predictor variables. The path diagram must subsequently address, or hypothesise how the causal influences from the regressors are transmitted to the ultimate dependent variable. This is, of course, less than straightforward since the sub systems within contemporary building projects interact in a complicated manner that is not yet well understood, thus a degree of simplification is considered inevitable.

It is logical that window systems will effect the overall environmental load imposed by buildings via two principal energy variables within their direct sphere of influence, namely the energy levels required in relation to thermal comfort and artificial lighting. Mathematical principals in relation to path analysis mean that the only variables that have to be specified within the path model are those concerning the window system itself and the sub- systems that interact directly with it. All other sub-systems that do not interfere directly with the window or glazing system can be excluded from precise specification within the model without compromising its ability to measure the size of the influence of the window system upon the overall environmental load *relative* to those other systems. The importance of the window system in determining the overall environmental impact of buildings can be measured relative to all of the other building sub- systems despite the fact that the models extensive design means that the exact influences of these other sub systems remain unmeasured.

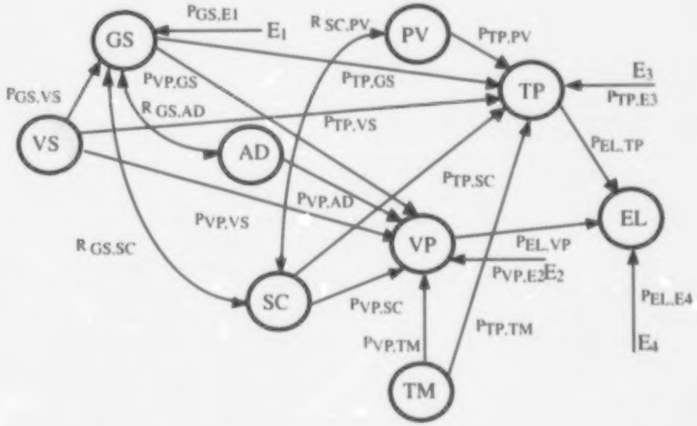
7 Specification of a provisional causal path model

The number of variables that could conceivably be specified within a causal path model having the stated evaluation objective is large. However, the more parsimonious the model, the more useful the results.

Therefore it is desirable to minimise the number of variables that are included within the full provisional causal path model. The process of identifying appropriate variables for inclusion with the evaluation model is ongoing. At the present time the variables included within the provisional model are as follows:-

- EL = Total Environmental Load (GJ/m2/year)
- TM = Thermal Mass
- SC = Solar Control Measures
- VS = Ventilation Strategy
- AD = Active Daylighting measures
- PV = Active Energy Technologies (eg. PV Cells)
- TP = Thermal Performance
- VP = Visual Performance
- GS = Window and Glazing Systems.

A provisional path analysis diagram is specified as follows:-



GS
P GS.E1
E1
R SC.PV
PV
P TP.PV
P VP.GS
P TP.GS
E3
TP
P TP.E3
P GS.VS
R GS.AD
P TP.VS
VS
AD
P EL.TP
P TP.SC
P VP.AD
EL
P VP.VS
VP
R GS.SC
P EL.VP
P VP.E2
E2
SC
P VP.SC
P EL.E4
P TP.TM
P VP.TM
E4
TM

Fig. 1: Provisional causal path model

8 Mathematical Specification

Considering the mathematical specification of path models in the normal manner, the provisional path model forwarded in Figure 1 can be described as follows. The dependent variables included in the provisional model may be expected to be determined by the following linear regression equations.

$$VP = f\{P_{VP.TM}\,TM + P_{VP.SC}\,SC + P_{VP.VS}\,VS + P_{VP.AD}\,AD + P_{VP.GS}\,GS + P_{VP.E2}\,E_2\} \quad (1)$$

$$TP = f\{P_{TP.TM}\,TM + P_{TP.SC}\,SC + P_{TP.VS}\,VS + P_{TP.GS}\,GS + P_{TP.PV}\,PV + P_{TP.E3}\,E_3\} \quad (2)$$

$$GS = f\{P_{GS.VS}\,VS + P_{GS.E1}\,E_1\} \quad (3)$$

$$EL = f\{P_{EL.TP}\,TP + P_{EL.VP}\,VP + P_{EL.E4}\,E_4\} \quad (4)$$

The influence of the window system upon the overall environmental load imposed by buildings (where this influence is denoted by I_{ws}) is found by:-

$$I_{ws} = \{P_{sp,ws} \times P_{el,sp}\} + \{P_{wp,ws} \times P_{el,wp}\} \qquad (5)$$

Finally, the influence of the other remaining sub systems and components evident within contemporary buildings upon the overall environmental load (where this influence is denoted by I_o) is found by:-

$$I_o = 1.00 - \{\{P_{sp,ws} \times P_{el,sp}\} + \{P_{wp,ws} \times P_{el,wp}\}\} \qquad (6)$$

9 Conclusion

A Life Cycle Assessment of the environmental impact of alternative window systems has been undertaken and this provides a useful design tool to improve the sustainability of buildings at the component level, however, it does not produce a complete understanding of how important window systems are in relation to improving the overall sustainability of buildings when they are considered as complete systems. It is considered that an investigation of the significance of window systems in relation to the overall environmental performance of buildings is justified. A causal path model is presently under construction to undertake such an investigation and to simplify, as far as possible, the analysis problem.

10 References

Boyle, R P. (1970) Path analysis and Ordinal Data. *American Journal of Sociology*. Vol 75, No. 4.

Field, F R III, Isaacs, J A and Clark J P (1994) Life cycle analysis of automobiles: a critical review of methodologies. *Journal of minerals, metals and materials society*. 46 (4) pp 12- 16.

Hammans, C J D. (1995) *IWA Conference Proceedings; 9th Congress*; Amsterdam.

Hendriks, N A and De Hoog, J. (1998) The importance of recycling in Life Cycle Assessment of Roof Systems. *IWA Conference Proceedings; 10th Congress*. Copenhagen, pp93-111, 10-12 June 1998.

Lawson, W R. (1995) Life Cycle Analysis of Windows. Proc. of Window Innovations '95. *State of the art window technologies for energy efficiency in buildings*. pp309-324. Toronto, 5-6 June 1995.

Little, B and Pederson B. (1993) Planning a Life Cycle Assessment. *Environmental Assessment of Products*. UETP-EEE, Helsinki.

Little, R J A. (1979) Linear Models and Path Analysis. *Survey Data, Report and selected papers*. ST/ESCAP/89.

SWCS (1990) Method of Path Coefficients- A Trademark of Sewall Wright; Madison, USA.

Weir, G F. (1998) Life Cycle Assessment of Multi- Glazed Windows. *PhD*. Napier University.

Weir, G F. and Muneer, T. (1998) Energy and Environmental Impact Analysis of double glazed windows. *Energy Conservation and Management*. Vol 39. No. 3/4 pp 243-256.

190 DESIGNING FOR DISASSEMBLY TO EXTEND SERVICE LIFE AND INCREASE SUSTAINABILITY

P. Crowther

Queensland University of Technology, Brisbane, Australia

Abstract

The dominant life cycle model of building materials and components is a linear system, which ends in demolition and disposal. If however, the act of demolition is replaced with the act of disassembly, more materials and components can be reused and recycled. This suggests a different life cycle model, one that accommodates an increase in service life. To achieve extended service life designers must design buildings for disassembly to facilitate the new steps in the life cycle and encourage the reuse and recycling of materials and components. Experience gained in the industrial design field and knowledge from attempts at creating disassemblable buildings can be used to create a set of guidelines for design for disassembly. Such a set of guidelines could be implemented to extend service life and improve environmental sustainability.

Keywords: disassembly, life cycle assessment, recycling, reuse, service life, sustainability

1 Introduction

Different parts of buildings have different life expectancies. This may be caused by the physical breakdown of the materials or components, but is more usually caused by a cultural or social change to which the building can no longer respond (Crowther 1998). As a result, while the structure of the building may have a service life of up to sixty years, the cladding of the building may only be suitable for twenty years. Similarly, services may only be adequate for fifteen years, and the interior fitout may be changed as frequently as every three years (Brand 1994). These different service lives do not generally however have a relationship to the actual physical serviceable life of the materials and components used. It is quite usual for 'temporary' parts of buildings to be fixed in permanently, preventing easy disassembly. At the end of the

Durability of Building Materials and Components 8 (Volume Three). *Edited by M.A. Lacasse and D.J. Vanier.* Published in 1999 by NRC Research Press, Ottawa ON K1A 0R6, Canada. ISBN 0-660-17742-0

material's or component's service life there is usually little option but for demolition with the associated waste disposal in landfills.

If buildings were designed for disassembly the alarmingly high rates of waste disposal from demolition could be avoided. Despite the potential economic and environmental benefits of disassembly, the practice has not been widely accepted in the construction industry. Overcoming the problems of designing for disassembly could result in an increase in the service life of materials and an improvement in environmental sustainability.

2 Existing model

A life cycle assessment of a building involves making an environmental assessment of all of the impacts that the project has at each of the stages of the building's life cycle. The commonly used model of life cycle assessment for materials and energy is based on a linear model of the building over time. This linear model of the building's life treats the project as a once through system in which the building progresses through a number of stages from inception, through design, construction, operation and maintenance, refurbishment, and finally to demolition. Similarly the model of the life cycle of materials is treated as a once through system passing from raw materials extraction, through materials processing, assembly and construction, operation, and finally to demolition (figure 1). This life cycle model is often referred to as a 'cradle to grave' model, where an assessment is made of all the impacts from the materials birth to its death (Yeang 1995) (Hansen et al. 1994).

In performing a life cycle assessment, each of the stages of the life cycle is assessed for the potential environmental impacts at that stage. These impacts will relate to the inputs and outputs to and from the system and may include, but not be limited to, natural resource depletion, energy use, pollution and waste production,

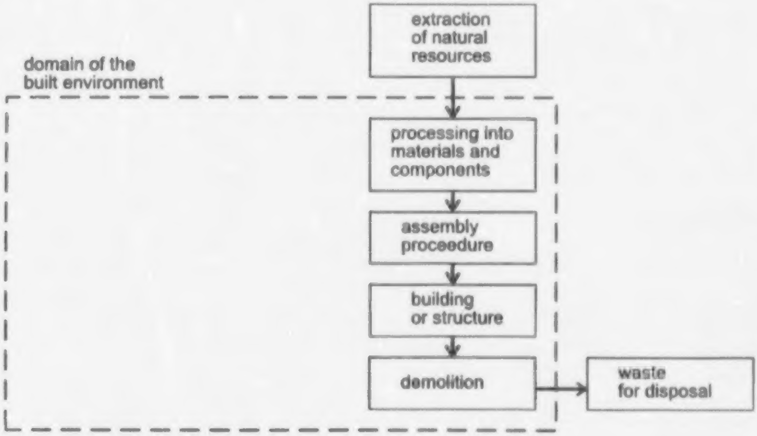

extraction of natural resources
domain of the built environment
processing into materials and components
assembly procedure
building or structure
demolition
waste for disposal

Fig. 1: Dominant model of life cycle of materials and components.

species and habitat loss, human health, and social issues. In particular these impacts typically include:

- depletion of scarce and non-renewable fuels such as oil and natural gas
- depletion of scarce materials such as exotic hardwood timbers
- depletion and contamination of scarce water supplies
- depletion and pollution of scarce farming land for non farming purposes
- generation of CO_2, CFC, and other airborne pollutants
- destruction of rare native plant species
- destruction of native animal habitat such as rainforests
- creation of health risks in the use and disposal of toxic materials
- creation of occupational health risks through biological and chemical pollutants
- contamination of the natural and built environment through pollution generation and waste disposal

If impacts are plotted against the stages of the buildings life cycle, a matrix is generated that can be use in making a life cycle assessment (figure 2).

If such a matrix is created for a generic building project, within the dominant mode of operation of the construction industry in industrialised countries, there will be negative impacts at all stages of the life cycle and in most areas of environmental impact. There are some areas though, that will repeatedly show up as sources of major potential problems. For example at the stage of natural resource extraction there are usually major impacts in the areas of resource depletion and species and habitat loss. At the stage of processing resources into materials there is usually a major energy use impact. Similarly during the stages of construction and use there is a major input of energy. At the far end of the life cycle the building reaches the stages of demolition and disposal. At this point there are usually major social impacts and problems of

	IMPACTS					
STAGES	energy use	resource depletion	waste & pollution	species & habitat loss	human health	social issues
extraction of resources		●		●		
processing materials	●					
assembly & construction	●					
building use	●					●
demolition						●
disposal of waste			●		●	

Fig. 2: Life cycle assessment matrix based on dominant life pattern of materials, showing areas of probable major negative impact.

waste and pollution generation. Some of these obvious impacts may however be avoidable.

While within current building industry practice the act of demolition does generate some material for reuse and recycling, the majority of materials are simply dumped as waste. In Australia there is an established industry dealing in reused and recycled building materials from residential building demolition. As much as 90% of materials and fittings are often reused or recycled. These practices are not however transferred to the commercial building industry where as little as 11% of demolition material is recovered for reuse. Up to 58% of the demolished material is salvaged for reprocessing, and the remainder is simply dumped into landfills (Salomonsson and MacSporran 1994).

In 1989 Australians disposed of almost two million tons of construction and demolition waste in landfills (Salomonsson and MacSporran 1994). In Canada the annual quantity of construction and demolition waste is approximately four and a half million tonnes and in Europe the quantities of demolition waste are measured in the tens of millions of tonnes per year (Christensen 1994) (Environmental Resources Limited 1980).

As well as these issues of waste and pollution generation there is the loss of the embodied energy that was used at the stages of natural resource extraction and materials processing. When the embodied energy of the demolition waste is assessed, as much as 45% of the building's embodied energy ends up lost into landfills (Tucker et al. 1994). While the calculation of embodied energy is only relevant for each particular project, there are general studies that show that the embodied energy in a residential building is equivalent to approximately ten years of operational energy. Similarly the embodied energy of a commercial building is equivalent to forty to fifty years of operational energy (Doyle 1994) (Treloar 1993). Given the alarmingly short life span of many commercial buildings, as short as thirty to fifty years, demolition then represents a loss of as much as 25% of the buildings total construction and operational energy use.

Embodied energy figures can also be compared with total national energy use figures. For example in the United States of America the building construction industry, including the energy embodied in building materials and components, represents approximately 6% of the nation's annual energy use (Hannon et al. 1978). The embodied energy lost in demolition therefore represents approximately 2.7% of the nation's total annual energy use, and a similar amount of embodied energy is lost in recycling and reprocessing materials rather than reusing them.

3 Alternative model

While this scenario of construction and demolition sees materials being used in a cradle to grave method, it is not the only model of life cycle. This cradle to grave model has the human analogy of birth and death, but it is a very limiting one for building materials and components. Human life is not a cycle but a linear chain of events. Similarly the common model of a materials life cycle is a linear chain of events with a beginning and an end. This concept of boundaries in time is actually not an appropriate representation of the life cycle of materials which do not travel a linear path but do in fact follow a true cycle of life in which they may have many incarnations within the built environment. Unlike humans, materials and components can be reused, remanufactured, recycled and reconfigured. Indeed many materials may never actually reach the grave.

Any assessment of the environmental impacts of a building material or component must take into consideration this notion that a material or component may pass through certain stages more than once.

If we recognise the potential for a true cycle of life, it is possible to divert the flow of materials from disposal and save the energy embodied in them by avoiding the strategy of demolition and disposal. If we add an alternative act of disassembly, a new model of a closed-circuit cyclical system can be created (figure 3). This new model incorporates a number of more environmentally attractive options that should reduce the quantity of waste and pollution generation, and reduce the loss of embodied energy, while extending the service life of materials and components.

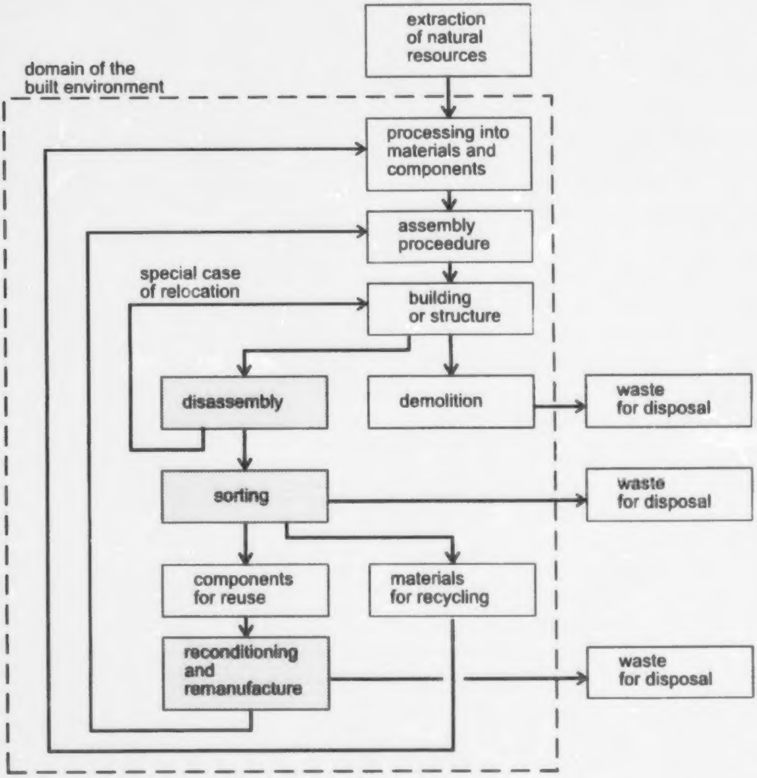

extraction of natural resources
domain of the built environment
processing into materials and components
assembly proceedure
special case of relocation
building or structure
disassembly
demolition
waste for disposal
sorting
waste for disposal
components for reuse
materials for recycling
reconditioning and remanufacture
waste for disposal

Fig. 3: Life cycle of materials and components for improved sustainability.

Industrial and product design practice has already recognised the potential for disassembly of components and materials for reuse and recycling. Many automobile manufacturers and computer manufacturers have an established program of product retrieval for disassembly (Rosenberg 1992). A study of the existing practice of designing for disassembly in industrial design reveals a number of new stages in the life cycle of materials and components (Dowie and Simon 1994). Similarly, a study of existing and historic examples of buildings that have been disassembled for reuse, reveal a number of new stages in the life cycle of building materials and components. In order to successfully achieve these new stages in the life cycle it is necessary to alter the way in which a building is designed. Based on a study of these architectural examples of disassemblable buildings, it is also possible to establish a number of design guidelines that can assist in the design of buildings for disassembly (Crowther 1998).

Firstly, the act of disassembly itself as an alternative to demolition. This involves the deconstruction of the building, or parts of it, in what is basically a reversal of the construction process. Some of the design guidelines that will assist in this process are:

- provide access to all parts of the building that are disassemblable to facilitate easy manoeuvring of components during maintenance and disassembly
- standardise the number of types materials and components to make disassembly quicker and more efficient
- use a minimum number of connections to allow easy and quick disconnection
- create separation of building structure, envelope and internal walls by using separate construction systems
- use an open system of construction rather than a closed system that would limit combinations of arrangement in future alterations
- reduce the number of different types of connections to reduce the number of different operations required
- use standard building practice appropriate to the location so that tools for disassembly are readily available
- use mechanical connections, not chemical connection
- provide identification of all points and methods of disassembly
- design components and materials to a size that is appropriate for the intended means of handling during disassembly
- allow for a hierarchy of disassembly related to component service life and the expected time till obsolescence
- allow for parallel disassembly, not sequential disassembly so that individual parts may be removed without disruption to other parts
- provide a manual on the total disassembly of the building to ensure that knowledge of the building is preserved.

Next, salvaged materials and components must be sorted. This will generate components for reuse, materials for recycling, and some waste for disposal. In order to better facilitate this process of sorting there are a number of guidelines that can be followed:

- provide a permanent means of identification of material and component using standard international identification markings to help avoid contamination in recycling
- minimise the number of different types of materials and components to reduce sorting time
- avoid hazardous and toxic materials that may make disassembly dangerous or create contaminants in recycling

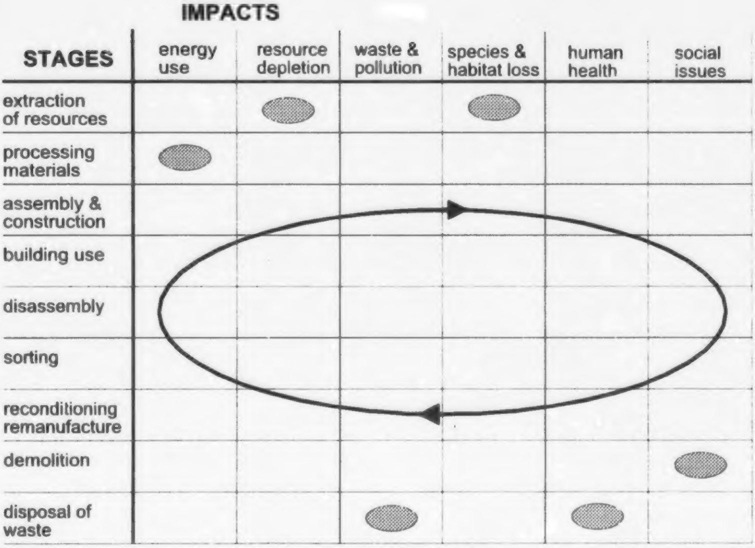
Finally, there may be a requirement to recondition or remanufacture the component to return it to the expected performance standards. This may typically include the replacing of parts or surfaces that have suffered excessive wear and the reshaping of deformed components and parts. Some of the guidelines to assist in this process are:

- reduce the number of wearing parts that may need to be serviced
- use sacrificial materials and components where wear is unavoidable and allow for their easy disassembly from the whole
- design to avoid permanent deformation during assembly, use and disassembly
- make components and materials modular and standard to improve compatibility with other components

There will also be other minor stages in this new system such as extra transportation and storage of the salvaged materials.

If we now look at a life cycle assessment using this new life cycle model we can identify any new areas of environmental impact that the new stages are likely to create. At the disassembly stage the major impact should be in the area of energy use. Depending on the extent to which the building is disassembled, the process may use almost as much energy as the assembly process. This energy use may have major problems of CO_2 and other pollution creation if it is generated using non-renewable resources such as the burning of coal and oil. All other negative impacts at this stage should be minor. At the stage of sorting there may be some generation of waste for disposal but this will obviously be considerably less than a demolition strategy will generate. Finally the process of reconditioning and remanufacture has the potential to use energy and resources but at a greatly reduced rate compared to the manufacture of new components.

Of most interest though are the negative environmental impacts that can be avoided using this strategy of disassembly. The life cycle assessment matrix for a disassembly strategy shows those major impacts that can be taken out of the cycle of materials (figure 4). At the natural resource extraction stage the impacts of resource depletion and species and habitat loss can be avoided or at least reduced. At the stage of processing resources into materials there is a potential major saving of energy use. Depending on the scale to which buildings and components are disassembled, there may be a significant saving of energy in the reassembly process. At the other end of the life cycle, the waste and pollution created by disposal of waste can be avoided or reduced, and finally the negative social impact of demolition may be avoided. These reductions in negative environmental impacts may add up to an overall improvement in the environmental sustainability of the built environment.



STAGES	energy use	resource depletion	waste & pollution	species & habitat loss	human health	social issues
extraction of resources		●		●		
processing materials	●					
assembly & construction						
building use						
disassembly						
sorting						
reconditioning remanufacture						
demolition						●
disposal of waste			●		●	

Fig. 4: Life cycle assessment matrix based on disassembly model of life pattern, showing areas of major negative impact that can be limited.

4 Conclusion

The common model of life cycle assessment, based on a cradle to grave concept of life, which is not a cycle at all, is not an appropriate way of representing the real life pattern of materials and components. This model sees materials and component created, used once, and disposed of. Materials however may be reused and recycled repeatedly avoiding the grave and extending service life. A more appropriate model recognises the act of disassembly as a strategic part of the life cycle that can help to achieve improved economic and environmental performance.

While the problems of disassembly have not been extensively investigated in the building industry, there are some important examples of buildings where there is a developed understanding of the principles of design for disassembly to improve reuse and recycling. This is generally performed for its economic savings, there are however also considerable environmental benefits. These include:

- a reduction in the energy used to process and manufacture the materials
- a reduction in the depletion of natural resources
- a reduction in the volumes of waste going to landfills and incineration
- a reduction in pollutants entering the environment

- an extension of service life to reduce embodied energy impact

Where the process of disassembly has been successfully incorporated into the life cycle of some products, the life cycle becomes a closed-circuit system in which the materials or components may pass through the system repeatedly. A life cycle assessment model that incorporates the stages of a disassembly strategy can highlight the environmental advantages of designing for disassembly, showing how it can extend service life and thereby improve sustainability.

While the guidelines presented here are in no way a complete list, it is hoped that this research will point towards a different way of approaching the use of materials and components, a way that recognises that they have multiple lives that may be measured on a different scale to human life. Further research on this topic is hoped to expand on these guidelines and to confirm the quantitative environmental benefits of implementing them in a design for disassembly strategy.

5 References

Brand, S. (1994) *How Buildings Learn: What Happens After They're Built*, Viking, New York.

Christensen, R. L. (1994) 'Quantification of Construction and Demolition Waste in Canada', in *Sustainable Construction* (ed) Kibert, C. J. Proceedings of the First International Conference of CIB TG 16, Tampa, Florida.

Craven, D. J., Okraglik, H. M. and Eilenberg, I. M. (1994) 'Construction Waste and a New Design Methodology', in *Sustainable Construction* (ed) Kibert, C. J. Proceedings of the First International Conference of CIB TG 16, Tampa, Florida.

Crowther, P. (1998) 'Design for Disassembly: an Architectural Strategy', Queensland University of Technology School of Architecture Interior and Industrial Design Winter Colloquium, Brisbane.

Dewhurst, P. (1993) 'Product Design for Manufacture: Design for Disassembly', *Industrial Engineering*, September, Vol.25, pp. 26-28.

Dowi, T. & Simon, M. (1994) 'Guidelines for Designing for Disassembly and Recycling', Manchester Metropolitan University, URL: http://sun1.mpce.stu.mmu.ac.uk/pages/projects/dfe/pubs/dfe18/report18.htm, 13th August 1998.

Doyle, F. (1994) 'Design for Deconstruction', *Architectural Review Australia*, Autumn, pp 86-90.

Environmental Resources Limited (1980) *Demolition Waste*, The Construction Press, Lancaster.

Hannon, B., Stein, R. G., Segal, B. Z. and Serber, D. (1978) 'Energy and Labour in the Construction Sector', *Science*, vol. 202, no. 4370, 24 November, pp. 837-847

Hansen, K., Krogh, H. and Dinesen, J. (1994) 'Environmental Assessment of Building Projects Based Upon a Life Cycle Approach', in *Sustainable Construction* (ed) Kibert, C. J. Proceedings of the First International Conference of CIB TG 16, Tampa, Florida.

Hassanain, M. A. and Harkness, E. L. (1998) *Building Investment Sustainability: Design For Systems Replaceability*, Minerva Press, London.

Rosenberg, D. (1992) 'Designing for Disassembly', *Technology Review*, November/December, pp. 17-18.

Salomonsson, G.D. & MacSporran, C. (1994) 'Recycling of Materials in Building Construction' *Conference Proceedings*, 1st International Conference on Building & the Environment, Watford, UK.

Treloar, G. (1993) 'Embodied Energy Analysis of Buildings Part 2: A Case Study', *Exedra*, vol. 4, no. 1, pp.11-13.

Tucker, S. N., Salomonsson, G.D. & MacSporran, C. (1994) 'The Energy Implications of Building Materials Recycling', *Strategies and Technologies for Maintenance and Modernisation of Buildings*, Proceedings of the CIB W70 Symposium on Management, Maintenance and Modernisation of Buildings, Tokyo, vol. 2, pp. 1101-1108.

Yeang, K. (1995) *Designing with Nature*, McGraw-Hill, New York.

191 THE ADOPTION OF HONG KONG'S ECO-LABELLING SCHEME FOR BUILDINGS

H.A. Davies

Hong Kong Polytechnic University, Hong Kong

Abstract

The Hong Kong Real Estate Developers Organisation have established a voluntary eco-labelling scheme for buildings in Hong Kong known as HK-BEAM (Hong Kong Building Environmental Assessment Method). It's use is as a tool to assess environmental impacts caused by buildings. It aims to encourage the adoption of more environmentally friendly building design. The assessment covers global, local and indoor issues. This paper reviews the benefits and difficulties of adopting this labelling scheme and highlights those areas where further work is needed to set international standards for the use of sustainable materials and increase the uptake of energy efficiency in building design and operation.

Keywords: Eco-labelling, building assessment method, life-cycle costing

1 Introduction

Developers in Hong Kong are taking a pro-active stance towards limiting the environmental impact of buildings in Hong Kong. The rapid building cycles in Hong Kong of demolition and construction generate large impacts on the environment from construction waste and use of resources. Building occupation itself can contribute to problems of global warming from the generation and high usage of energy. The Hong Kong Building Environmental Assessment Method (HK-BEAM) is a voluntary method for assessing the environmental impact of new or existing air-conditioned commercial buildings. The scheme has been funded by the Real Estate Developers Association of Hong Kong and is operated by the Centre for Environmental

Durability of Building Materials and Components 8 (Volume Three). *Edited by M.A. Lacasse and D.J. Vanier*. Published in 1999 by NRC Research Press, Ottawa ON K1A 0R6, Canada. ISBN 0-660-17742-0

Technology Ltd. (CET) the executive arm of the Private Sector Committee on the Environment. It is based on the UK's Building Research Establishment Environmental Assessment Method (BREEAM) for offices (Prior, 1993) with suitable adaptations made for the conditions particular to Hong Kong. BREEAM was launched in 1990 as the first "green" labelling scheme for the housing market in the UK. It has been expanded to cover a range of commercial, retail and industrial buildings and one quarter of all UK office buildings are now assessed. To date in Hong Kong, 4 new office buildings and 6 existing buildings have been assessed under HK-BEAM. Schemes like BREEAM and HK-BEAM can be regarded as types of eco-labelling for buildings.

What is the purpose of eco-labelling schemes? They are often market led initiatives to encourage more environmentally friendly building design and energy efficiency in use. But how useful are eco-labelling schemes such as HK-BEAM at evaluating environmental performance? Do they cover enough issues? Are they attractive enough to make people want to voluntarily use them? Can they have an effect on the long term performance of buildings in the environment?

This paper examines the HK-BEAM scheme and summarises its objectives. One "excellent" rated case study is detailed. As a first step in answering some of the questions raised above as to their purpose and value, a review of the items included in HK-BEAM follows. A second part of this critique will look at extension of the eco-labelling scheme and alternative building environmental performance assessment methods.

2 Review of HK-BEAM

HK -BEAM is one of a growing number of schemes being introduced to increase market awareness of green issues. Companies are increasingly recognising that good environmental sense is also good business sense. Energy efficiency saves running costs, waste minimisation uses less resources, clean production avoids pollution rather than needing time, money and resources for cleaning up afterwards.

2.1 HK-BEAM has a number of objectives:

- To reduce the long term impact that buildings have on the environment;
- To raise the awareness of the large contribution which buildings make to global warming, acid rain, and depletion of the ozone layer as well as local environmental issues;
- To promote and encourage energy efficient buildings and building service systems and equipment;
- To reduce the unsustainable use of increasingly scarce resources such as water, timber and natural materials;
- To improve the quality of the indoor environment and hence the health and well-being of the occupants;
- To provide recognition for buildings where the environmental impact has been reduced;

- To set targets and standards which are independently assessed and so help minimise false claims or distortions;
- To enable developers, operators and users to respond to a demand for buildings which have less impact on the environment and to help stimulate such a market.

The scheme gives recognition for enhanced environmental performance in the design, operation and maintenance of buildings. Certification to HK-BEAM is completely voluntary and undertaken by independent specialists. Fifty six "best practice" environmental criteria are defined for a range of design and management issues. Premises are assessed against the criteria and 'credits' awarded where the criteria are satisfied. The results of the assessment are presented on the HK-BEAM certificate as a rating of *Fair, Good, Very Good* or *Excellent*, according to the number of credits achieved.

Table 1: Issues covered in HK-BEAM

Global Issues	**Local Issues**	**Indoor Issues**
Purchasing policies	Electricity maximum demand	Operation and maintenance
Energy efficiency programme	Water conservation	Metering and monitoring
Electricity consumption	Legionnaires disease from wet cooling towers	Biological contamination
Ozone depletion	Vehicular access	Indoor air quality
Storage for recyclable materials	Transport and pedestrian access	Hazardous materials
	External noise	Radon
		Lighting
		Indoor noise

The global, local and indoor issues are expanded and fully detailed in the following tables:

Table 2: HK-BEAM's requirement of the "Global Issues and Use of Resources"

Global Issues and Use of Resources		
Parameters	**Possible Credits**	**Credit Requirement**
Electrical energy consumption	13	• Design of low Overall Thermal Transfer Value (OTTV) • The use of energy efficient lighting • Demonstration of low lighting load • The use of heat recovery system • Confirmation of low air conditioning load
Ozone depletion	4	• Specification of low ozone-depletion potential refrigerants • Implementation of refrigerant leakage programme
Use of timber	3	• Specification of durable and reusable formwork system • Utilisation of sustainable timber
Storage for recycling materials	1	• Design of separate storage space

For existing offices, 3 other parameters (overall environmental policy, environmental purchasing policy and energy efficiency programme) can be given credits, but parameter of "use of timber" is not required.

Table 3: HK BEAM's requirement of the "Local Issues"

Local Issues		
Parameters	**Possible Credits**	**Credit Requirement**
Electricity maximum demand	3	• Demonstration of low peak-electric demand
Water conservation and wastewater discharge	3	• Adoption of separate water meters, flow controls and automation of water flows
Recycled materials	2	• Specification of 50% or more recycled materials • Separation of waste on site
Legionnaires' Disease	1	• The use of wet cooling towers by the Code of Practice - Prevention of Legionnaires Disease
Noise from the building	2	• Design not to exceed more than 5dB from the nearest noise sensitive receiver

For existing offices, 2 other parameters (transport and pedestrian access, and vehicular access for servicing and waste disposal) can be given credits, but parameters of "recycled materials" and "wastewater discharge" are not required.

Table 4: HK-BEAM's requirement of the "Indoor Issues"

Indoor Issues		
Parameters	**Possible Credit**	**Credit Requirement**
Metering and monitoring equipment	4	• Installation of separate electricity meters
HVAC system commissioning	3	• Specification of air, water and HVAC systems in accordance with the CIBSE and BSRIA guidelines
Operations and maintenance	2	• Set up operations and maintenance manual • Demonstration of proper management
Biological contamination	1	• In compliance with the Code of Practice – Prevention of Legionnaires Disease
Indoor air quality	4	• Specification of ventilation rate in accordance with CIBSE or ASHRAE guidelines
Hazardous materials	1	• Specification of formaldehyde emissions in accordance with the British Standard • Adoption of unleaded paints • The use of pre-treated timbers
Lighting	3	• Fitting of high-frequency ballasts lighting • In compliance with CIBSE guidelines on illumination • Demonstration of good daylight factor
Indoor noise	2	• Demonstration of external and internal noise levels in accordance with the British Standard

For existing offices, 4 other parameters (building maintenance, operation and maintenance of building services systems, mineral fibres and radon) can be given credits, but parameters of "HVAC system commissioning" and "hazardous materials" are not required.

The first building to achieve an 'excellent' rating under HK-BEAM is a 25 storey plus 5 basement storey, Grade A office building (Lincoln House) completed in April 1998 with a GFA of 31,688 sq. m. Some of the special features that allowed it to be rated as 'excellent' are detailed in Table 4.

Table 5: Special features of Lincoln House

ENERGY	• OTTV of 17.97W/sq.m. half of statutory value • No incandescent lamps used in general areas of building • Heat recovery used to pre-cool the supply air by the exhaust air • Adequate provision of monitoring equipment items such as temperature sensors, flow meters provided for major A/C equipment • Proper testing and commissioning for major HVAC systems to ensure efficient operation of the systems • Maximum use of daylighting to minimise electric lighting
INDOOR AIR QUALITY	• Separate exhaust air duct dedicated for connection of building tenants' ventilation system to allow direct exhausting of tobacco smoke and other types of indoor air pollution • No lead primers or paints; MDF with minimum formaldehyde emissions; no preserved timber • Use of preservative fluids on site limited to essential operations
TRANSPORT	• Covered pedestrian access provided to encourage use of public transport • Loading and unloading areas segregated from pedestrian access routes • Only the minimum number of carparking spaces provided to discourage driving to work
WASTE	• Separate space provided for collection of waste paper and other recyclable materials • New materials in permanent works all contain over 50% of waste, by-product or recycled materials
OZONE PROTECTION	• Non-CFC refrigerant used for chiller plant • Automatic refrigerant leak detection system used for early warning • Refrigerant recovery equipment for use during servicing
TIMBER	• Corrugated steel sheeting or recycled composite fibreboard used for hoardings • Durable and reusable timber formwork used • Solid timbers for permanent works are specified to be from sustainable sources and contractors must provide proof of origin of timber used • Recommendations of the same made to tenants for fitting out

The construction of Lincoln House was 'championed' by one of the members of the Real Estate Developers Association that funded the development of HK-BEAM. It provides a model of what is possible for other developers. However, the benefits of this rating scheme as a marketing tool have yet to be proven in Hong Kong. There has been limited uptake to date of the HK-BEAM initiative by developer's in Hong Kong. Ten buildings have been rated and Lincoln House has few tenants to date – most probably a result of the current economic recession in Hong Kong. Environmental consciousness has a low priority in much of Hong Kong development. The government is taking action and the Planning, Environment and Lands Branch (1996) has emphasised the need to "raise public awareness of the environment and the impact our daily lives make upon it" so that the territory's development can be better sustained. Hong Kong is making progress. It may be possible to identify the benefits of eco-labelling in Hong Kong, as they have been in the UK, where a survey by Bhatti and Sarno (1996) identified that 12% of people put 'high standard of energy efficiency' as their top priority when buying new homes. This result is attributed to the longer term introduction and increasing use of energy rating of new homes and eco-labelling systems available having an effect on demand. However, at present, Hong Kong is still characterised by patterns of excessive consumption. Are there limitations to the eco-labelling techniques that could be improved so that the scheme becomes more useful and attractive or are there other techniques to explore?

3 Limitations of green-labelling schemes

HK-BEAM, whilst being a useful marketing tool and raising awareness of environmental issues, has some limitations. The choice of credits could be seen as limited and require up-grading even within the short time-span of it's introduction. For example, a company that complies with the requirements of an Environmental Impact Assessment could feel entitled to the award of credits for its efforts at limiting environmental impacts during construction. The potential for expanding the list is large with currently no international agreement on what must and could be included in these kind of assessments. Environmental impacts come from construction, utilisation and maintenance and demolition. Further criteria in HK-BEAM should therefore address these impacts.

There are also questions of quantifying some of the qualitative measures. The current assessment scheme requires both quantitative and qualitative measures to be rated. Are some credits not more important than others? How can you compare an essential health risk like Legionnaire's disease against space for storage of recyclables? How much does a pedestrian access cost and how much is it worth? How beneficial is it an encouraging the use of public transport? Difficult to answer questions – but Hong Kong developers want to be able to put monetary values on everything to justify the cost of any measures they take and the extra cost of upgrading to try and achieve further credits.

HK-BEAM suffers from a number of criticisms that have been levelled at it's parent scheme – BREEAM. Although BREEAM has been praised as a valuable marketing tool for the property industry, some have criticised it as a layer of bureaucracy (Macneil, 1995). Additionally, BREEAM is not based on a full life-cycle analysis for buildings. A building that has poor energy consumption can still achieve a high score through other factors (Curwell, 1996).

A serious limitation of green-labelling schemes is their non-accounting for the amount of embodied energy. The period over which the building is to be used is of key importance in determining the relative significance of the energy that goes into the production of a building's constituent materials and components, and the energy used in the building during occupation. Whilst energy-in-use costs are being reduced by the use of thermally efficient materials, these materials are often more energy-intensive to produce and increase the embodied energy content of buildings. If a building has a "short life", then the effect is to increase the relative significance of embodied energy costs compared to energy consumed in use (Connaughton, 1992). In Hong Kong, major refurbishment cycles can be as short as 5 years and building replacement cycles 15 to 20 years. The embodied energy of these buildings may be as high if not higher than the energy used in occupying them over their actual life spans. Reducing energy running costs is therefore of limited value in relation to the overall value of energy used in the materials comprising the building stock.

5 The significance of embodied energy in building materials

As an example of the significance of embodied energy, about 10% of the UK's annual energy consumption is used in the production of building materials (Digest of UK Energy Statistics). The building materials industry is relatively energy intensive. This is because building materials are generally high volume, low-value products.

There is difficulty in comparing materials without common units of measurement – generally monetary value of output is available, but it may not include the same measured energy inputs. What energy inputs should be included? Should 'indirect' energy requirements of materials and machinery used in the process of manufacturing building materials be included and what about the costs of raw material extraction and transport? Research by Stein et al (1981) has identified 5 "key" materials as accounting for over 50% of the total embodied energy of new buildings (steel and iron 23%, concrete 14%, timber and wood 9%, bricks and clay 5%, cement 2%). Government and developers interested in reducing environmental impacts and reducing energy consumption could focus on opportunities for minimising material use or substitute lower energy-value materials.

The direct energy consumed in the production of a building is a relatively low proportion of the total energy and has been estimated as 17% for the USA (Stein et al 1981). This is because construction is largely a labour intensive process involving the assembly of already manufactured or processed materials.

Construction is thus a highly energy consuming industry – but the proportions of energy used to produce the materials, to construct the buildings and to run and maintain them will vary according to the life span of each building. Short life spans will mean embodied energy values will be relatively higher. Short life spans will also mean that environmental impacts from construction work will be more significant. The combination of these issues can only be sensibly resolved through life-cycle analysis.

6 Life-cycle analysis

Life-cycle analysis offers greater potential for assessing the environmental impacts that occur throughout the life-cycle of a building. A building requires inputs of fuels, raw materials, water and land. It creates outputs of a variety of pollutants to air, water, land and noise. The processes inbetween involve extraction of raw materials and their conversion to construction products. The construction process itself, transportation, the use and maintenance of buildings, demolition and waste management again require materials and energy (Krogh and Hansen, 1994).

The difficulties lie with being able to quantify the relative inputs of materials and energy and the environmental impacts that make up the total life-span of a building. Without such quantitative data and weights we have no real basis to assess building environmental performance at the decision and policy level (Levin, 1997). Progress is being made – expected life-spans of building materials and components have been estimated (NBA, 1985) and Haseltine (1975) has calculated the energy intensities of several different construction forms. It is also possible to select environmentally preferable building materials to improve a building's environmental performance (CET, 1995). Further work of this nature is required to make life-cycle analysis a practical option.

7 Conclusions

Demands for sustainable buildings are likely to grow. This presents opportunities for the construction industry. HK-BEAM provides an excellent management tool for prioritising and communicating real improvements in the performance of buildings, resulting in cost savings through the more efficient use of energy and resources, increased occupant's satisfaction through an improved indoor environment, recognition for good management practices, increased marketability and the further enhancement of the corporate profile.

However, it has limitations in that it assesses a limited number of issues. It does not consider environmental impacts during construction and makes no attempt to allow for the costs of embodied energy in building material. It therefore offers only limited analysis of the total environmental impact of a building over it's life-span.

A systematic, standardised assessment tool to evaluate the total environmental impact of a building is still urgently required. One such method is that offered by life-cycle analysis. However, this again has limitations since at present there are difficulties in calculating the total energy costs and environmental impacts over the life of a building.

8 References

Bhatti, M. and Sarno, C. (1996) Who greens the housing market? *The Environmental Impact of Land and Property Management* (ed. Y. Rydin), John Wiley and Sons Ltd., pp. 65-80.

Centre for Environmental Technology, Ltd. (1995) *HK-BEAM 1/95(New Offices). An environmental assessment for new air-conditioned office buildings.* Hong Kong, October 1995.

Connaughton, J. (1992) Real low-energy buildings: the energy costs of materials, in *Energy Efficient Building: A Design Guide*, (eds. S. Roaf and M. Hancock), Blackwell Scientific Publications, pp.87-100.

Curwell, S. (1996) Specifying for greener buildings. *Architects' Journal*, 11 January, pp.38-40.

Haseltine, B. A. (1975) Comparison of energy requirements for building materials and structures, *The Structural Engineer*, 53, September No. 5, pp.357-365.

Krogh, H. and Hansen, K. (1994) *Data needed for environmental assessment of building projects.* Proceedings of Building Research Establishment Conference, Watford, UK, 1994.

Levin, H. (1997) Sustainability: on the limit. *HAC – Building Services Engineering*, July p.24.

Macneil, J. (1995) The weighting game, *Building*, 27 January, pp.48-49.

NBA, (1985) *Maintenance cycles and life expectancies of building components and materials: a guide to data and sources.* NBA Construction Consultants Ltd, London.

Planning, Environment and Lands Branch (1996) *Heading towards sustainability*, PELB, Hong Kong.

Prior, J. J. (Ed). (1993) *BREEAM/New Offices Version 1/93: an environmental assessment for new office designs.* Building Research Establishment Report 2nd edition 1993.

Stein, R. G. et al (1981) *Handbook of energy use for building construction.* US Department of Energy , Reassignment, DC.

192 GREENING OF CANADA'S NATIONAL MASTER SPECIFICATION

T. Dunbar and B.R. Kyle

Public Works and Government Services Canada, Hull, QC, Canada

Abstract

Initial development of the National Master Specification (NMS) of Canada began in the late 1960's to avoid duplication by the federal government departments involved in construction. Through collaboration with private sector specification writing organizations, this document is now national in scope and accepted as the primary master construction specification by the Canadian construction industry. Canadian federal government regulations required that all departments undertake proactive and verifiable steps towards sustainable development. Six areas were identified as having the greatest environmental impact, and therefore, the highest priorities in the "greening" process. The criteria used to determine the environmentally responsible choices that have been added to the NMS are based on consideration of life-cycle assessment and environmentally responsible design. The communication and awareness heightening methods used to assist in decision making, relative to the "greenness" of available options, are discussed in this paper. The paper details the action plan implemented to integrate sustainable development and durability principles and elaborates on the future application of the greened NMS in the construction practices specified by Public Works and Government Services Canada (PWGSC).

Keywords: green specifications, national strategy, sustainability, environmental design

1 Introduction

In the late 1960s, the Canadian federal government departments involved in construction decided to amalgamate their individual master construction specifications into a single document, as the Government Master Specification

Durability of Building Materials and Components 8 (Volume Three). *Edited by M.A. Lacasse and D.J. Vanier*. Published in 1999 by NRC Research Press, Ottawa ON K1A 0R6, Canada. ISBN 0-660-17742-0

(GMS). The document was used by all federal government departments and by all architectural and engineering consultants working for the federal government. Positive pressure from the private sector as well as the great success, acceptance and quality of the document, lead to it becoming considerably more national in scope by the mid-seventies.

Thanks largely to the involvement of the private sector, primarily Construction Specifications Canada (CSC) and their predecessor, the GMS had evolved after several years, into the document that we now know as the National Master Specification (NMS).

As well as reducing the duplication of effort, the NMS was also seen by the federal government as a unique tool for transferring technology and government policy. It is still used extensively for this purpose today.

1.1 NMS framework

The NMS is generic in nature. It does not identify manufacturers by name, trademark or brand name. It is commonly referred to as a "delete master"; providing, as choices, the characteristics and criteria of all materials, products, systems, assemblies and procedures used in the construction industry. This allows specification writers to delete the choices not relevant to specific projects.

The NMS, available in English and French, is accepted as the primary master construction specification by the Canadian construction industry and has over 650 sections covering virtually all aspects of construction (16 divisions of ***MasterFormat* ©**[1]).

Division 1 Sections of the NMS address administrative and procedural aspects of construction and construction control. Divisions 2 through 16 deal with the technical issues and are material, product or process specific. For example, a Division 1 section related to shop drawings explains how shop drawings should be submitted, their size and how many copies are required, whereas, the technical section for, say, doors would outline the requirements that should be included on the shop drawing such as hardware locations.

2 Objectives of greening exercise

Most people desire the "greening" of regular aspects and procedures of their lives. By taking more care to perform all facets of construction and maintenance in as environmentally prudent a way as possible, this desire may become a reality. Direction is needed to identify the materials, products, components, systems, assemblies and procedures that are perceived to be the least harmful or potentially beneficial to the environmental wellbeing. It is the Government of Canada's role, as environmental custodian for its citizens, to see that adequate measures are taken to attain that wellbeing. The NMS is an invaluable information dissemination tool toward this objective.

The long term selection of appropriate materials and application of sound

---

[1] MasterFormat© is a North American construction industry formatting document jointly owned and published by Construction Specifications Canada (CSC) and the Construction Specifications Institute (CSI) in the United States.

practices and procedures will together lead to greener, more durable facilities and the sustainability of the environment as a whole. Building tenants will enjoy healthier working environments. Society will benefit from clean air, clean water, usable land and resources for future generations.

2.1 Partnership with construction specifications Canada

When the GMS became the NMS in the mid-seventies, Construction Specifications Canada (CSC) was the main private sector organization that had input into the document. They were, and to some extent still are, the main "window of opportunity" for private sector specifiers to effect change in NMS sections. CSC had a parallel organization with co-ordinators and reviewers of NMS sections to assist in the development of the NMS to meet the needs of the private as well as the public sectors. Today, now that the NMS is more fully developed, CSC works in conjunction with the NMS Secretariat through the CSC Technical Studies Committee.

2.2 Government impetus

2.2.1 Legal requirements

Sustainable development, defined as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs"(United Nations 1988), has become a key goal of the public policy of the federal government both domestically and internationally over the last decade.

Amendments to the Auditor General Act on December 15, 1995 (Canada Gazette 1995) required each federal government department to table a Sustainable Development Strategy (SDS) prior to December 31, 1997. PWGSC and other departments, fulfilled this requirement on schedule and the PWGSC plan is available to the public (PWGSC 1997) (http://www.pwgsc.gc.ca/comm/sds). In order to create a proactive atmosphere with a verifiable indication of progress, the responsible Ministers are required to update their SDS every three years and report annually on their progress towards sustainable development.

2.2.2 PWGSC's sustainable development strategies

To provide adequate detail for PWGSC's corporate response to the legislated requirement, the various departmental branches developed organization specific sustainability documents. The Real Property Services Branch (RPSB) of PWGSC developed an SDS that sets out the goals, objectives and actions required to integrate the strategies into policy and operations (PWGSC 1996b). The RPSB strategy forms an integral part of the overall SDS for PWGSC.

The SDS of the Real Property Services Branch identified several areas of paramount concern. They were:

- Toxic or hazardous substances and waste management;
- Ozone depleting substances;
- Non-hazardous solid waste management;
- Energy and water efficiency in facilities;
- Contaminated sites management; and
- Land and marine/fresh water activity management.

The staff at the National Master Specification in turn established where the NMS could be used as an effective tool to implement the SDS objectives. They developed an action plan that directly supported the integration of the RPSB sustainable development principles into its policies and operations (PWGSC 1998).

The connection between moral obligations to the Canadian public, the 1995 Auditor General's Report through to the "greening" process and the updating of the PWGSC SDS is depicted in Figure 1.

3 Greening methodology

By addressing the sustainability issues, the NMS provides a tool that supports RPSB and facilitates in the integration of a comprehensive environmental management system. This will assist RPSB in demonstrating due diligence, and will ensure that environmental performance is achieved and sustained according to established objectives. Considerable work had already begun on "greening" efforts but the legal requirements of the Auditor General's Report (Canada Gazette 1995) gave a heightened significance and corporate support to the undertaking.

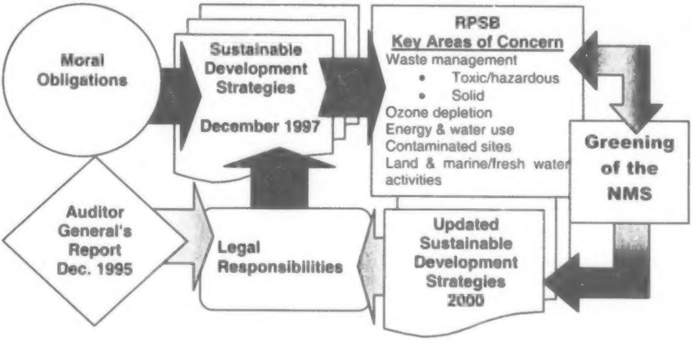

Moral Obligations
Sustainable Development Strategies
December 1997
RPSB
Key Areas of Concern
Waste management
• Toxic/hazardous
• Solid
Ozone depletion
Energy & water use
Contaminated sites
Land & marine/fresh water activities
Greening of the NMS
Auditor General's Report Dec. 1995
Legal Responsibilities
Updated Sustainable Development Strategies 2000

Fig. 1: Towards sustainable development objectives

3.1 Revision of the NMS

The environmental group at PWGSC undertook a study to determine which sections of the NMS were most environmentally sensitive (PWGSC 1995). This exercise produced a list of all NMS sections and their priority for the "greening" process. The highest priority was given to those sections covering subject matter that was the most environmentally threatening.

The RPSB SDS was further examined in detail to see which sections of the NMS could be updated to meet the sustainable development requirements as well as to identify gaps in the coverage of the NMS for sustainable development purposes.

In each of the identified sections, various options in material, construction or demolition practice were proposed and given the designation of an "environmentally responsible choice". The NMS Secretariat contracted various environmental consultants to address the most significant items as quickly as possible. The criteria used by the NMS to determine the environmentally responsible choices which have been added to the NMS are based, for the most part, on life cycle assessment and environmental design principals (CSA Z760-94 1994; CSA Z762-95 1995). Once the most environmentally sensitive sections had been taken care of, the "greening" of the remaining sections was rolled into the regular update process. With the planned review and update schedule, all sections of the NMS will be "greened" by 2001.

The NMS has over 650 sections that are updated on a continuous three-year cycle. That means that any section that is updated and published in 1999 will come up for review and re-publication in 2002. The NMS Secretariat does not view the "greening" of a section as ever being completed. As with the other technical aspects of any section, the environmental aspects continue to change as technologies advance. Hence the need for a continuous three-year updating cycle.

The interaction of the "greening" schedule and the NMS review and updating cycle is illustrated in Figure 2.

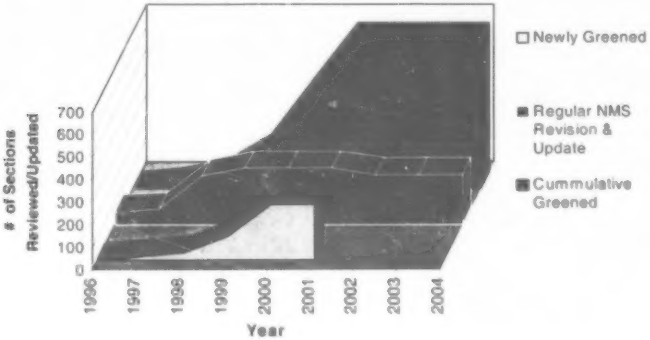


Fig. 2: NMS fully "greened" by 2001

3.2 Application of assessment criteria

Although the goal is to "green" all of the NMS sections, emphasis was placed upon addressing the six areas identified in the RPS SDS (Section 2.2.2) and the NMS sections that could immediately be targeted for action.

The NMS database of sections was scrutinized to decide on the most effective way to improve these areas.

3.2.1 Toxic or hazardous substances and waste management

There were several places in the NMS where this was addressed. General actions included the development of:

- A new Division 1 section for the removal and disposal of hazardous materials;
- A new Division 1 section for the removal and disposal of toxic materials; and
- A new technical section for the removal and disposal of hazardous materials.

Three existing sections dealing exclusively with asbestos abatement were updated to include the most current practices, codes and regulations for the asbestos abatement industry.

A new technical section was developed for the storage, safety and management of polychlorinated biphenyl (PCB) materials. Specifically, this section addresses: decontamination requirements for reuse and recycling of PCB transformers; storage site management; leak and spill safety and labeling. The decontamination information was obtained from Canadian PCB decontamination standards (CCME 1995) and the storage site management information came from the Canadian environmental legislation (CEPA 1988). Also, 20 existing sections within the NMS were updated to include information advising against the selection of PCB containing products.

The two sections that deal with the installation of aboveground and underground storage tanks were updated to reflect more environmentally responsible practices. Additions have been made throughout both sections encouraging maximum leak and spill protection. The national fire protection code (NFC 1995) and the codes of practice for storage tanks (CCME 1993, 1994) were the primary references used for this initiative. A new section was also written for the removal of underground storage tanks. The new section outlines the basic procedures that must be followed when removing underground storage tanks, including government regulations, safety requirements and licensing.

3.2.2 Ozone depleting substances

Seventeen sections of the NMS were identified as having an impact on ozone depletion. These were reviewed by specialists in that field and updated with more environmentally responsible choices and practices.

3.2.3 Non-hazardous solid waste management

The existing sections that tackle construction related demolition were updated and two new NMS sections were developed to deal with deconstruction and dismantling. The first new section was a Division 1 section addressing the administrative and procedural aspects of deconstruction and dismantling, and the second new section was a Division 2 section addressing the more technical aspects of deconstruction and dismantling.

One other important initiative that was undertaken by NMS staff in this area was the negotiations that took place with the committee that was updating ***SectionFormat*** © [2]. A new article heading in Part 1 of ***SectionFormat*** © entitled "Waste Management and Disposal" was included in the updated version of the format document. The addition of this heading has far reaching consequences. The NMS (and every other master construction specification) now has a consistent place to address this problem in every specification section.

As a result of this new article in ***SectionFormat*** ©, the NMS has produced a new Division 1 section and is in the process of including a Waste Management and Disposal article in each and every technical section in Divisions 2 through 16. An extract from the NMS, that addresses some of the waste management issues for concrete for bridge decks is presented in Figure 3 (PWGSC NMS 1999).

---

[2] ***SectionFormat***© *is a North American specifications formatting document jointly owned and published by Construction Specifications Canada (CSC) and the Construction Specifications Institute (CSI) in the United States.*

3.4 WASTE MANAGEMENT	Prior to concrete pours, designate locations or uses for excess concrete. .1 Use excess concrete for: [additional paving] , [post footing anchorage] , [swale rip-rap reinforcing] , [mud slab] , [flowable fill] , [footing bottom] , [retaining wall footing ballast] , [storm structure covers] , [underground utility pipe kickers] , [storm pipe flared end section] , [toe wash protection] , [shoulder and toe outfall restraints for temporary erosion pipes.]

SPEC NOTE– ENVIRONMENT: — Prior to concrete pours, designate a location for cleaning out concrete trucks. Options include: company owned site for such a purpose (meeting all federal, provincial and regional environmental standards), or a remote area of the site to be paved later in project.

Fig. 3: Extract from the NMS Division 3 Section 03301

3.2.4 Energy and water efficiency in facilities

Twenty-eight existing sections of the NMS were identified as having a direct effect on energy conservation through the use of energy efficient products, equipment and practices, and were updated with information outlining more environmentally responsible choices. This mainly targeted products and equipment that use energy such as electricity, gas or oil directly.

3.2.5 Contaminated sites management

The existing NMS database of sections did not address the problems associated with contaminated sites. A new Division 1 section was developed to address the administrative and procedural aspects associated with contaminated sites. Two technical sections were developed to deal with particulars of contaminated site management. The first deals specifically with hydrocarbon contamination issues and the other with various forms of site contamination.

3.2.6 Land and marine/fresh water activities management

Four existing NMS sections were identified as having an impact on wastewater management. These sections were reviewed and updated to include the most current environmentally responsible choices and practices. Six existing sections relating directly to marine activities were reviewed and updated. These sections touch-on materials and procedures for dredging channel excavation, pontoons and other mooring devices, and the preservation of waterways.

4 Communications and awareness

The NMS includes information aimed directly at specification writers to assist them in making informed and correct decisions about the various choices and options available to them in the master specification when they are preparing their project specific contract documents. Further work has attempted to convey sustainable design issues to the architectural community (PWGSC 1996a).

The most difficult thing in an initiative such as has been undertaken by the NMS staff is how to communicate to the rest of the construction industry exactly what is being done. The NMS staff has approached this in several different ways.

4.1 NMS structure

The vehicle that the NMS uses to highlight information for specification writers is called a **SPEC NOTE**. Each paragraph that contains an environmentally responsible choice is further highlighted with "**SPEC NOTE ENVIRONMENT**" (as in the example of Section 3.2.3 Fig. 3.).

Although the NMS is not intended to influence the design, it is sometimes used as an aid to making design decisions. This is most likely to happen when the designer is also the specifier and has a limited technical knowledge on a particular subject matter. In such instances, the tendency is for the specifier to select the first of multiple options that may be available.

Since the NMS staff are well aware of this phenomenon, if one of the options is preferable and more commonly used, that option is generally placed first in the list. This is not a rule and usually does not apply to choices that involve measured dimensions or quantities.

4.2 Workshops and presentations

There have been workshops for federal government people from across the country that are involved with writing construction specifications and contract documents. A cross-country tour to all regions of PWGSC presented the RPS SDS and the "greening" of the NMS. In the fall of 1997, the NMS Secretariat held an Environmental Update Forum and meetings with interested private sector groups, particularly trade and manufacturers' associations. The purpose of this forum was to inform the Canadian construction industry about recent changes to the NMS and to initiate constructive dialogue between the NMS and the rest of the Canadian construction industry. This proved to be an enormous success and resulted in the NMS Secretariat receiving increased assistance from various Canadian construction associations and organizations.

4.3 Dissemination

The Federal Government does not sell the NMS directly, but distributes the document through three private sector publishers, one of which is CSC. The other two publishers are the Royal Architectural Institute of Canada (RAIC) and the Electronic Tender Network Inc. . Of the three, CSC has the largest volume of sales of the NMS. The publishers take the raw intellectual data in Standard General Mark-up Language (SGML) and convert it for use with conventional word processing software. Each publisher may, with the approval of the NMS Secretariat, add enhancements to assist specifiers in the editing process.

The most important tool that has been used to communicate this information is the NMS itself. The NMS staff has encouraged as many public and private sector groups and individuals to become involved in the NMS review and update process. The NMS staff has received "buy-in" to the whole review and update process from most of the Canadian construction industry.

5 Future impact and improvements

The PWGSC Project Delivery System (PDS) (PWC 1989) outlines standard procedures that are to be followed for effective execution of a construction project. The PDS details the methods to be used from the conceptual phase of a project through to the commissioning of any facility. These procedures are not in themselves unique. Their significance lies in the potential impact on the "greening" process and the long-term effects upon the environmental friendliness of the PWGSC asset base. Since the PDS stipulates that the NMS be used to specify products and processes, the "greening" of our construction practice is dependent upon the successful "greening" and dissemination of the NMS. PWGSC is currently studying the potential effects, and suitable timing, of routinely using environmental specialists or specifiers at designated stages of a project's execution.

As the PWGSC SDSs evolve, with the updating every 3 years, there will be changes to the structure and content of the NMS. The document is living and is required to respond to the changes in the public's desire for sustainability in much the same way it adapts to technological advancement.

6 Conclusions

The "buy-in" of the process for "greening" of the NMS has shown that the Canadian construction industry as a whole is making a concerted effort to develop a construction contract documents tool.

The greened NMS embodies the principles of sustainable development and can be integrated not only into the operations of federal government buildings, but for buildings owned and operated by other governments and private sector entities.

Participation in this initiative by the private sector has enhanced the outcome and highlights the opportunities for achieving more sustainable building practices in the future.

7 References

Canada Gazette, Part I (1995) *An Act respecting the office of the Auditor General of Canada and sustainable development monitoring and reporting, c. 43, s.1.*, Ottawa, Canada.

Canadian Council of Ministers of the Environment (CCME) (1995) *PCB Transformer Decontamination Standards and Protocols*, CCME PN1205, 35 pg., Winnipeg, Canada.

Canadian Council of Ministers of the Environment (CCME) (1993b) *Environmental Code of Practice for Underground Storage Tank Systems Containing Petroleum Products and Allied Petroleum Products*, March, CCME EPC-LST-61E, Winnipeg, Canada.

Canadian Council of Ministers of the Environment (CCME) (1994) *Environmental Code of Practice for Aboveground Storage Tank Systems Containing Petroleum Products*; August, CCME EPC-LST-71E, Winnipeg, Canada.

Canadian Environmental Protection Act (CEPA), c. 22 (1988) - *Storage of PCB Material Regulations*, (SOR/92-507), Ottawa, Canada.

Canadian Standards Association (CSA) (1994) CSA Z760 -94 - *Life Cycle Assessment*, Rexdale, Canada.

Canadian Standards Association (CSA) (1995) CSA Z762 -95 - *Design for the Environment*, Canadian Standards Association, Etobicoke, Canada.

NFC (1995) *National Fire Code of Canada*, National Research Council of Canada, Ottawa, Canada.

Public Works Canada (PWC) (1989), *Project Delivery System*, Architectural and Engineering Services, ISBN: 0-662-56852-4, Ottawa, Canada.

Public Works and Government Services Canada (PWGSC) (1995) *The Environmentally Responsible Construction and Renovations Handbook*, Real Property Services Branch, Internal Document EA 22e, Ottawa, Canada.

Public Works and Government Services Canada (PWGSC) (1996a) *An Architect's Guide for Sustainable Design of Office Buildings*, March, Real Property Services Branch, EA 37e, Ottawa, Canada.

Public Works and Government Services Canada (PWGSC) (1996b) *RPSB Sustainable Development Strategy*, December, Internal Document, Real Property Services Branch, Ottawa, Canada.

Public Works and Government Services Canada (PWGSC) (1997) *Sustainable Development Strategy*, April, Real Property Services Branch, P35-99/1997, Ottawa, Canada.

Public Works and Government Services Canada (PWGSC) (1998) *Action Plan for the Greening of the NMS in Support of the RPS Sustainable Development Strategy*, Internal Document, Real Property Services Branch, Architectural & Engineering, Technology Directorate, Ottawa, Canada.

Public Works and Government Services Canada (PWGSC NMS) (1999) *National Master Specifications*, Real Property Services Branch, Architectural & Engineering, Technology Directorate, National Master Specifications Secretariat, Hull, Canada.

United Nations (1988) *Our Common Future*. World Commission on Environment and Development (UNWCED), Oxford University Press, Toronto, Canada.

193 SUSTAINABILITY BY STRENGTHENING THE RELATION BETWEEN DISCIPLINES INVOLVED

S. Durmisevic, S. Sariyildiz, E. Durmisevic, and J. Brouwer
Delft University of Technology, Delft, The Netherlands

Abstract

A sustainable development is becoming an important part of future city planning and the built environment in general, which requires multidisciplinary work and closer co-operation of disciplines involved. Three main disciplines that need to work together are civil engineering, architecture and urban planning. Regarding the built environment these disciplines interact on many levels. In this paper we will analyse the roles of these disciplines and accentuate the crossroads in decision making that are of vital importance for achieving a sustainable city. A sustainable city is a city where the history and future are interwoven into present, rather than building cities to be used only by one generation with nothing left for the future. Therefore, adaptability and flexibility are the key issues for a sustainable future of our built environment.

Keywords: Sustainable development, multidisciplinary work, adaptability, flexibility

1 Introduction

In the last decade there is a growing concern regarding environmental problems which was discussed in the latest meeting at the United Nations (UN) – World Commission on the Environment and Development. In the Brundtland Report, it was stated that the building industry is the greatest consumer of the world's natural resources and energy as well as the greatest waste producer [DIOC96]. For example:

- 50% of material resources taken from nature are building related
- over 50% of national waste production comes from the building sector

Durability of Building Materials and Components 8 (Volume Three). *Edited by M.A. Lacasse and D.J. Vanier*. Published in 1999 by NRC Research Press, Ottawa ON K1A 0R6, Canada. ISBN 0-660-17742-0

- 40% of the energy consumption in Europe is building related [Anink96]

Higher ecological efficiency could be achieved by prolonging the life cycle of the building and its components. The future development in general should be directed towards reusing, recycling and waste reduction (3 R's). Re-assembly is a precondition for the 3 R's. That means that the way of constructing is a key for flexibility and therefore sustainability as well.

"Sustainable development is development which meets the needs of the current generation without compromising the ability of future generations to meet their own needs" [Brundtland96].

To achieve sustainable development the different disciplines that are involved in the building process should have sustainability as a starting point at all levels of the decision making. In earlier times, rather strict hierarchies were present, while today a networking concept [Jong98] is more appropriate. In contrary to the hierarchical decision-making, the networking provides an opportunity for more efficient integration of knowledge from diverse disciplines in early design phase. The direct feedback from the disciplines involved provides an optimal design solution and in such way reduces the problems in later stages of the building process.

For the built environment three main aspects can be distinguished:

1. Sustainable Planning
2. Sustainable Design
3. Sustainable Exploitation

It is obvious that sustainable planning has as a final goal sustainable design and exploitation, otherwise the word "sustainable" would not be justified. To further demystify and redefine the definition of sustainability, the following definition is given:

Sustainable development is such development that through its planning provides such design solutions that will enable its continuous exploitation in the future (Fig.1).

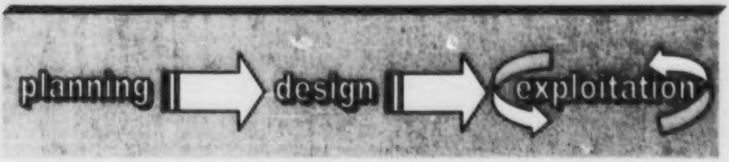


Fig. 1: Sustainable built environment

The following chapters will provide a closer insight of these three aspects and parties/processes involved.

2 Sustainable planning

A city is a self-contained system, fulfilling many functions at the same time. These functions are common all around the world (Table 1). A city is seen as a social, cultural and economic centre, or having in mind already existing cities we could say:

"... existing built form embodies historical, social, economic and cultural values" [Jenks96].

Table 1: City components and functions

No.	Functions	City components
1.	private and communal needs	buildings
2.	mobility	street, roads, railways, etc.
3.	service infrastructure	telecommunication, water pipes, etc.
4. etc.	social activities	squares, parks, etc.

In order to give some guidelines for a logical organisation of the above-mentioned components, many discussion and debates are held which involve different disciplines. At this stage a global framework for regional development is sketched.

Four groups are most active at this level, namely:

- regional planner
- environmentalist
- politician
- economist

Their main role is to form a vision for the future development that is based on predictions regarding population growth, economy, politics, having at the same time in mind the environmental consequences.

The word "planning" perhaps has a too strong suggestion since it seems to be something that is arranged through the last detail. But it is exactly at this level of decision making that the planning is the most vague and only indicate possible outcomes. The decisions made should represent concepts to be incorporated in later stages. More concisely, it is a planning of future concepts and ideas that is based on today's demand and awareness of the consequences for the future. Such concepts that are today being discussed and that have great influence on future actions and developments are:

- towards more compact cities and multi-layered ground utilisation (intensifying ground usage where it is most precious - in the city centres)
- underground as an important component of future planning
- greater flexibility of built structure
- recycle and reuse of building components and reduced production of building waste

- environmental responsibility of planners, designers and users, etc.

According to the book "The Compact City - A Sustainable Urban Form?" it is impossible to state that there is one city form which is more sustainable than the other, since it is very much location and culture dependent. From this we could conclude that sustainability means a variety of forms. It is also stated that the success of sustainability greatly depends on the policy making. There is a need for common global goals that would lead towards sustainable solutions, but on the local level, there should be enough flexibility left to interpret these global solutions according to the local requirements [Jenks96]. The success of sustainability depends on its technical and psychological qualities.

Once there is an initiative for realization of a project, multidisciplinary planning should take place. The concept of this cycle is illustrated in the following figure, showing on one side processes and on the other side involved parties (Fig. 2):

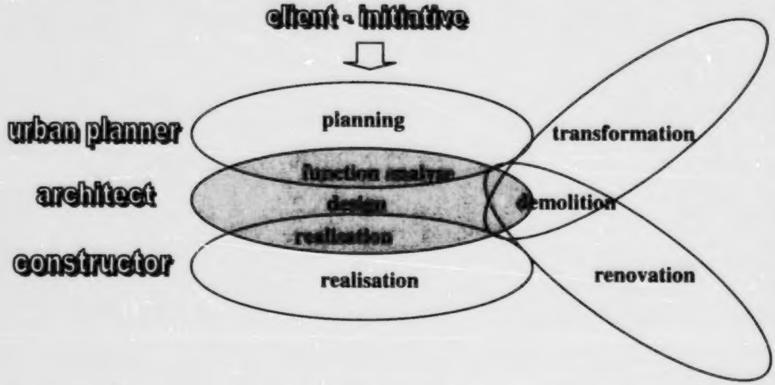


Fig. 2: Planning processes and parties involved

2.1. Open planning

Unpredictable fluctuation in market economy demonstrates that the market itself is in a state of transformation. Investors are less willing to risk developing huge projects that take few years to complete. Therefore, they prefer to invest in developing only a segment, rather than the whole project [Friedman97].

Adaptability to changing market trends, thus more user oriented planning, has become extremely important today. Instead of designing urban subdivisions and commit their developers to long and costly change process later, one could propose an approach that would allow changes with reduced interventions at the later stage. OBOM research group at TU Delft is developing such an approach.

- it recognises hierarchical order in decision making process between independent levels of decision making
- it allows flexibility and freedom in the design of independent levels in a manner, which reflects the technological developments and the needs of society at that time
- it recognises different life cycles for different levels in the built environment
- it distinguishes three main levels being: tissue, support and infill. They are separated but yet well co-ordinated [Durmisevic98]

3 Sustainable design

"The process of architectural design aims to define a physical form that will achieve certain functional and behavioural objectives in a particular context" [Carrara94].

In other words, the act of architecture is putting building elements together while creating one integrated whole. Therefore, we could say that the main roll of the designer is to define this process. It is important to realise that the fundamental changes needed to obtain sustainable environment, thus sustainable building, are related to the materialisation and realisation of the building process.

To achieve a building's physical integration has become increasingly complex since architecture should incorporate many disciplines in order to satisfy toady's requirements. Previously, the architecture had its own rules. It was easy to build considering that there was less choice regarding used materials (mainly wood, brick and stone). Today, after the hyper-development of our society based on technological boom, the design process has undergone enormous transformation. Buildings are not conceived of few materials any more, but with specialised products (produced on production lines) which have to satisfy high requirements of our modern life styles. Architecture is therefore not independent any more, but it relies on many different building specialists and partners during the design and building process (Fig. 3). It has to be practical in relation with other disciplines, since current transformations of our society are forcing architects to deal with:

- changes that have taken place in the nature of the materials
- increased speed of the construction caused by industrialisation of architecture
- climate changes
- life-style changes

Furthermore, all above-mentioned issues are related to the global question of sustainability, which is becoming a moral issue today.

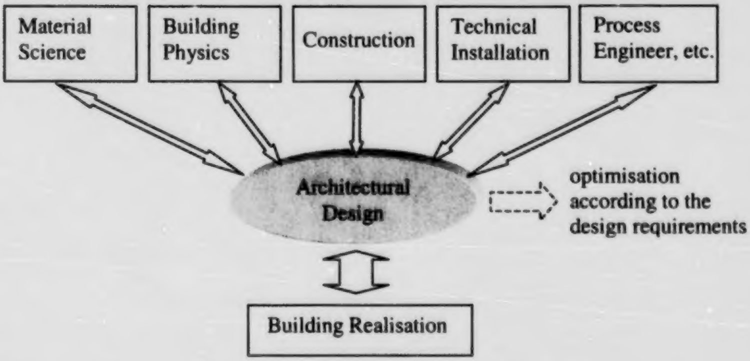


Fig. 3: Integrated design, based on concurrent engineering

Sustainable design has to provide two aspects:

- sustainable aesthetic quality (psychological aspect)
- sustainable technique

The conventional approach to sustainable construction is usually related to long-lasting buildings, whose life cycle should be at least 70 years. On the other hand the economic duration of certain phases in the use of the building is generally shorter than the technical life span of most of its components. Unlike the conventional approach to durable constructions, which is focused on durability of buildings and their materials, one could suggest a new approach that is focused on short life cycle of different phases of use of the building. Every new phase of the building use implies new requirements and spatial organisation, hence changes. In order to provide the sustainability of new buildings, we can't approach architecture in the same static way as we did before. The life cycle of the building has to be extended, which can be achieved only by extending its possibility to accommodate different functions. Such an approach is related to the materialisation and realisation process, which has direct consequences for building behaviour in the future.

This means that during the design process, the exploitation and transformation of the building should be considered seriously (fig. 4).

The Fig. 4 illustrates the life cycle of a building in context of sustainable design, which depends on repetitive sequences (from materialisation to transformation design). From the relations drawn in this diagram it is obvious that the number of different phases in building use depends on materialisation of a building and weather it will provide proper technical solution for every new requirement.

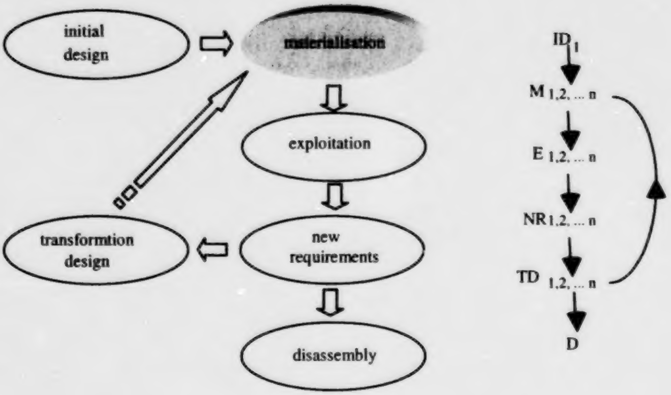


Fig. 4: Building life cycle

Around the year 2000 more people will be living in polluted cities than in the countryside [Horden98]. That means that more than 50% of the entire population will live in a man-made environment and these percentages will increase even more.

Sustainability of our environment could be achieved only through its flexibility and adaptability to future changes, wherein design process and materialisation play the most important roll. Unlike the traditional "time consuming" planing process were all disciplines were working independently, flexibility involves interaction and networking between different disciplines in order to reach optimal solutions.

Aside from flexibility of planning, sustainable design should be focused on juxtaposition of the materials and functions of building parts at joints. The interface between components plays a crucial role in re-assembly, which is an ultimate form of recycling and reusing. In that respect the development towards systematisation and modulation of building parts into subsystems presents the way to achieve more effective buildings with controlled use of energy, raw materials and less man-power [Horden98].

4 Sustainable exploitation

Sustainable exploitation means having a building adaptable to future requirements, which is provided through minimum:

- energy use
- raw material use
- waste produced
- time invested

- maintenance

In the past buildings were design only to satisfy the function required at that exact time. This traditional approach to the design usually implied total demolition at the end of the building life cycle.

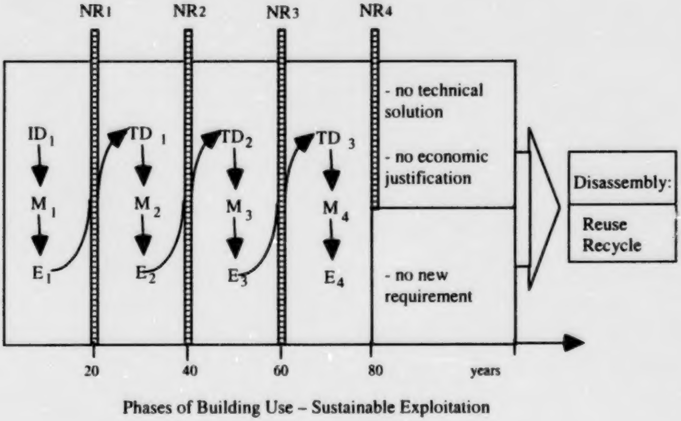

NR1
NR2
NR3
NR4
ID1
M1
E1
TD1
M2
E2
TD2
M3
E3
TD3
M4
E4
- no technical solution
- no economic justification
- no new requirement
Disassembly:
Reuse
Recycle
20
40
60
80
years
Phases of Building Use – Sustainable Exploitation

Fig. 5: Phases of building exploitation

Sustainable design should provide possibility to reuse building components or recycle elements when the building reaches the end of its life cycle. That will happen when there is no suitable technical solution or economic justification for changes based on new requirements. The same will happen if there is no new requirement at all. In that sense a sustainable design is achieved. This is illustrated in the figure above (Fig. 5).

5 Conclusion

Environmental concern was the main initiator for sustainable development, since building sector is one of the major contributors to global pollution, raw material and energy consumption. This should therefore initiate changes at all planning levels (city level, building level and exploitation) in order to reduce the negative environmental impact of the built environment. Planning should provide maximum freedom on all levels of decision making, which can be obtained through sustainable materialisation. This would in the end provide durable exploitation.

6 References

Anink,D., Boonstra, C. and Mak, J. (1996) Handbook of Sustainable Building. *An Environmental Method for Selection of Materials for Use in Construction and Refurbishment*

Brundtland Commission (1996). CiudadCity - nature and technology 1/1996. *Towards Sustainable Cities*, pp. 112

Carrara, G., Kalay, Y.E. and Novembri, G. (1994) Knowledge-Based Computer Aided Architectural Design. *Knowledge-Based Computational Support for Architectural Design,* Elsevier

DIOC (1996) The Sustainable Urban Environment. *Research Programme – The Ecological City*. TU Delft

Durmisevic, E. (1998) Conference Proceedings of "The 20th Century urban Planning Experience. *Deconstruction After Demolition,*15-18 July 1998, Sydney – Australia

Friedman, A. (1997) Journal of Urban Design. Design for Change – Flexible Planning Strategies for the 1990's and Beyond, vol. 2, No 3, 1997

Horden, R. and Vogler, A. (1998). DETAIL Journal. *Building with Systems*

Jenks, M., Burton, E. and Williams, K. The Compact City - A Sustainable Urban Form?, E & FN Spon

Jong, H. (1998) Boosting presentation. *De Toekomst van de Bouw*.

194 PRODUCT FEATURES THAT INFLUENCE THE END OF A BUILDING

N.M.J. Guequierre and J. Kristinsson

Delft University of Technology, Delft, The Netherlands

Abstract

In the Netherlands, 14 million tons of demolition and construction wastes are produced every year, of which about 80 percent is recycled on a material level, as rubble used for road subbases. The government however, prefers product reuse above material-reuse or landfill and incineration. Yet, there is no tool which would allow a decision maker to make a considered choice for the most Eco-efficient end-of-life scenario for a building product. The end of life of a building is defined as the last phase of the lifecycle of a building and can be subdivided in the following stages: demolition/ disassembly; transport; sorting, cleaning, repairing and storage of products and materials; landfill, incineration, material recycling and product reuse. These various options for the end of the life of a building are called End of Life Scenarios (ELS).

Optimizing for the end of life of a building has its consequences for the design process. When an architect tries to design for a certain ELS, he must choose the appropriate products and optimize the connections between those products. Suppose, an architect wants to design a building that can easily be disassembled and that consists of building products most of which are suitable for reuse. Of course he does not want to reach this aim at any price. He seeks a balance between environmental profit and the life cycle costs of a design, the costs that have to be made for the end of life of a building.

To handle this problem we will not concentrate on the whole building, but at components of the building: the building products. This research project aims to develop a tool to assess both the qualitative and quantitative aspects of the end of life of a building product that effect the product's environmental impact and life cycle costs. This article describes product features that influence the end of life of a building product. A case study of an office building that has a very short lifetime of twenty years, designed for disassembly and recycling, illustrates the first results of this analyze tool.

Keywords: Life Cycle Assessment (LCA), environmental impact, end-of-life scenario, life cycle costs (LCC), design for dismantling, design for durability, demolition, product reuse, material recycling, BELCANTO.

Durability of Building Materials and Components 8 (Volume Three). *Edited by M.A. Lacasse and D.J. Vanier*. Published in 1999 by NRC Research Press, Ottawa ON K1A 0R6, Canada. ISBN 0-660-17742-0

1 Introduction

A few decades ago a lot of attention was paid towards flexible and dismantable buildings [Reinhardt and Bouvy 1985]. The promoters of this trend assumed that this flexibility is a great benefit for the users of the building, but unfortunately it never became common, and the attention decreased. Nowadays, at least in the Netherlands, the building industry is again interested in dismantable buildings. Congresses and a considerable grant from the government for demonstration projects, show the importance of this trend.

Although it is still not very common, the design of a dismantable house should be no problem, because there are a lot of building products you can combine to create a dismantable building. The flexibility of this building will become greater and the possibilities to reuse the building products will also become greater. The building industry considers the dismantability, next to the flexibility, as a possible solution for environmental problems [Congress Industrial Flexible and Demountable building, 1998]. However, the question is whether reuse of building products is the best alternative for creating less pressure on our environment? Is reuse of products better than other possible scenario's, like recycling of materials, landfill or incineration, in general or just in a few specific cases? In this paper we also describe the product features that influence these scenario's, using a case study that serves as a handle.

2 Evaluation of End-of-life scenario's (ELSs) with BELCANTO

The four scenario's mentioned in the last section, reuse of products, recycling of materials, landfill and incineration are defined as End-of-life Scenario's (ELSs). A way to determine the best possible end-of-life scenario of a building is to use a Life Cycle Assessment method (LCA). At the moment, a lot of methods are available, computerized or not, that help us make a considerate choice [Guequierre et al 1998].

However, until now LCA's concentrate primarily on the production and use of products. The end of life of building-products is still underexposed and a lot of data of demolishing and dismantling are still missing. But this lack of data is not the only problem; it is also very difficult to allocate environmental load to the first and second life of a product. For example, if concrete is used in a building, it is possible to allocate the energy used for breaking the concrete to the first life, as well as to the second life of the material as road subbase. These are complicated issues that have to be addressed before a considerate choice can be made between various ELSs for building products.

Another limitation of the actual LCA's is that not all aspects that have their influence on reusability or recyclability are integrated in the LCA's. For example, product features, like connections with other products, remaining lifespan, ergonomics and safety, have influence, but are not systematically used in decision making.

To conclude, a tool for an architect, or a building product developer, or a researcher is missing, to support the choice between reuse of products, recycling of materials, landfill or incinerating as the end-of-life scenario of a certain building product. Recently, we suggested a possible design for such a decision support system [Guequierre et al. 1998]. Figure 1 shows a scheme of this system, called BELCANTO (Building End of

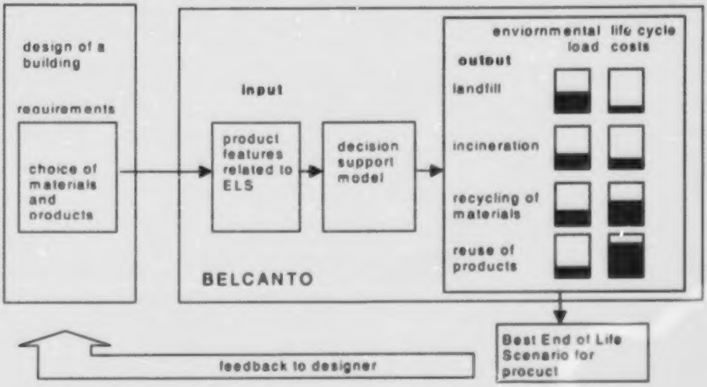

design of a building
requirements
choice of materials and products
input
product features related to ELS
decision support model
BELCANTO
output
enviornmental load
life cycle costs
landfill
incineration
recycling of materials
reuse of products
Best End of Life Scenario for procuct
feedback to designer

Fig. 1: Scheme of the decision support system BELCANTO

Life Cycle Analyze Tool). The output of BELCANTO will be at least the environmental load of a building product. However, decision makers need also economic aspects, thus the life-cycle costs of the various ELSs must also be part of the output. Furthermore, some qualitative deliberations, like the ease of dismantling, are added to the output. The input of BELCANTO will be a building product. We described several product features that are relevant for the decision support system and in fact these features are the input of BELCANTO [Guequierre et al. 1998].

3 Office XX: a case study

The purpose of this case study is to illustrate how the various product features influence the environmental load and life cycle costs of ELSs. We choose 'Office XX' as an example because:

1. The office is designed to be dismantled after 20 years and the building products can be reused again or the materials can be recycled. This building has therefore the possibility to examine all ELSs for each building product in contrast to other offices: they are made quite often from in situ concrete which can only be recycled on a material level and can not be reused as a product;
2. the office is rather small, 2000 m^2, and has a limited number of elements (about 60 different types).

3.1 Office XX

Post Ter Avest architects in Rotterdam got the idea to build an office with a lifespan of only 20 years in summer of 1996. They decided to drop the idea that building for eternity was the best solution to build in an environmentally friendly way, and they are convinced that it is possible to build an office that combines the trend of the short economical lifespan of an office with the trend of making sustainable buildings. They decided to gear the lifespan of building products to the economical lifespan of a building. The idea is that the building should decay after 19,5 years and collapses after 20 years.

The financier of this building, Wereldhaven N.V., has several reasons to invest in this project. The main reason is the responsibility towards the environment, but of course there are less noble motives to join the projects. Most office buildings must be refurbished after only 20 years because of the wishes of a new tenant. Refurbishment is very expensive, and is a large operation, because office buildings are rarely designed to be dismantled. Besides these refurbishing costs, they also expect that costs for dumping demolition and construction waste will rise in the future.

Another reason to invest in this project are the additional advantages, like the energy saving by adapting the façade structure in an other building, and the experience with sustainable building.

3.2 Design process

A team, consisting of employees of the constructor, the architect, the Eindhoven University of Technology (concerning the installation), and the contractor designed the office. The design team met several times during the development of Office XX to discuss design solutions and costs. Design strategies of the design team are:

1. The building should be flexible and removable, producers of building products were asked to give a guarantee that the product can be recycled afterwards;
2. The design is divided in two levels, 'support' and 'fill-in';
3. The choice of materials is harmonized as much as possible with the life cycle of the building (20 years).

3.3 Description of the building

The office with a surface of 2000 square meter is designed for 160 employees.It is divided in two floors of 1000 square meter (Figure 2). In the middle of the rectangle is the entrance; at both ends are stairs. In the middle of each half, 30 square meters are reserved for sanitary units and installations.

The main construction of XX is a skeleton of columns and beams made of multi-layered, glued pinewood (Swedlan). The very strong wood, combined with steel cables at the bottom of the beams makes a slim construction with a great span (5x6 m.). The ground floor is made of concrete, the first floor is made of pine beams and underlayment and filled with sand for noise reduction.

The façade is entirely three-layered glass and forms together with a curtain a climate façade. The curtain is a screen, gradually changing in transparency, attached to cylinders at the floor and ceiling, and can be rolled in such way that the transparency is adjusted to the sunlight. All measures on energy saving like the three-layered glass and the climate façade result in a very energy efficient building. A recent study on

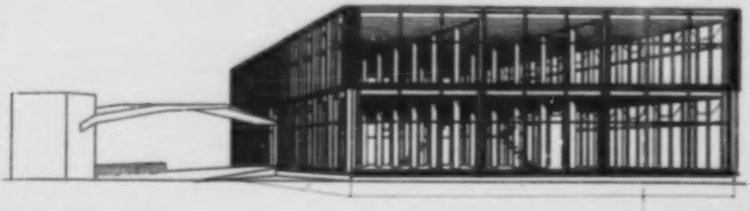


Fig. 2: Office XX

environmental aspects shows that the total environmental load of this building, compared with a 'normal' office, is about 40 % lower, due to saving energy [Knapen et al.1998].

4 Product features related to End of life scenarios

This section discusses various product features that influence the scenarios at the end of the life of a building. We distinguish three ELSs: reuse of the product, recycling of materials and landfill/incineration.

4.1 Reuse of product

The reuse of a product requires that the product is as undamaged as possible. This requires a careful way of disassembling and a well-considered way of design and construction of a building. Important stages in the reuse of products are shown in Table 1: demolition/dismantling, transport, repair and the actual reuse.

Table 1: Overview of product features that influence life cycle costs and life cycle analysis and reusability for reusing building products

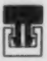
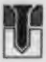
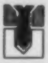
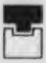
ELS	**INPUT BELCANTO**	**OUTPUT BELCANTO**		
Reuse of products	**Product features**	**LCC (guilder)**	**LCA (ecopoints)**	**Reusability (qualitative)**
Demolition/ Dismantling	• connection to other components	dismantling costs	energy costs, emissions	ease of dismantling
	• ergonomics and safety	-	-	working conditions
	• percentage drop-out	costs a piece	ecopoints a piece	-
Transport	• size and weight	transport costs	ecopoints for transport	-
Repair	• connection to other components	damage, and thus costs for repair	-	-
	• percentage repair	costs a piece	ecopoints a piece	-
	• sort of repair	repair costs	energy, material	-
Reuse	• remaining lifespan	price performance relation	ecopoints-performance relation	-
	• reliability	-	-	applicability in new building
	• out dated product	-	-	utility in future
	• quantity	-	-	probability of reuse
	• economical profit	saving costs not using a new product	-	-
	• environmental profit	-	not using a new product	-
Sum		**total costs reuse of product**	**total environmental load reuse of product**	**qualitative judgement reusability of product**

- **Connection to other components**

We suggest there are three types of connection: fixed, half-fixed, and non-fixed. *Fixed connections* can be divided into two types: *chemical fixed connections* like glue, cement, PU foam, and solder, or *mechanical fixed connections* like clicking. Characteristics of this type of connection are that either the product is damaged by the connection, or the product is covered with the material used for the connection. In either case, the product has to be cleaned or repaired before reuse is possible.

Half-fixed connections are connections that can be disconnected, but not as easily as non-fixed connections. An example of this type of connections is when nails are used, or screws are rusted. It is not certain that the product is intact after disconnection. A percentage will be damaged, dependent on the type of connection. The connection itself will most likely to be damaged as well.

Table 2: Analysis of connections of three product of XX

type of connection / element	fixed connection		half-fixed	non fixed connection	
	chemical	mechanical		extra part for connection	form-connection
					
floor element (concrete hollow core slab)	other concrete floor elements collumn support (poured with concrete)				
span bar construction (steel)			cross bars (16 pins)	wooden beam column	
window frames ground floor		other window frames, with connection slat		other window frames, ground floor floor element first floor aluminium profiles	

difficult to dismantle — easy to dismantle

Non-fixed connections are easy to undo. Examples of this type of connection are screwed connections that are not rusted and click-connections that can be unclicked (mechanical non-fixed connections). The connection is not damaged and can be reused. [Timmermans 1985].

In table 2 connections of office XX are analyzed. The concrete hollow core slabs of the ground floor are connected to other building products in a fixed way. Product reuse will be less attractive because it is difficult to loosen them from other products and more damage will occur. The window frames of the ground floor are connected in a non-fixed way to many other building products. It will take considerable amount of time to disconnect these building products (high life cycle costs), but it is possible to remove them undamaged (less environmental impact).

- **Dismantling versus demolishing**

XX is a rather dismantable building; only a few building products can not be removed in an easy way and have to be demolished. Dismantling has some advantages in comparison with demolishing; e.g. dust and noise can be avoided. When the dismantling of XX is done in a careful way, safety and ergonomics should be no problem.

Disassembling buildings to obtain building products requires more work than demolishing buildings and this work must be done in a safe and healthy way, because it concerns human activity. During disassembly, large and generally heavy objects have to be moved. Since this is accurate work, people will be close to these objects and will run the risk of becoming injured. Furthermore workers may get ill by prolonged exposure to noise and dust, caused through for example, sawing stones.

- **Percentage unusable**

The very large threefold glass panes of XX run the risk of breaking and it is obvious that during dismantling a higher percentage of the panes will be destroyed in comparison with wooden columns. When columns are damaged, it is plausible that the damage can be repaired, and the percentage that is unusable is negligible. A higher percentage of not reusable products causes a higher price a piece, both economically and environmentally.

- **Size and weight**

The size and weight of products determine the costs of transport and the environmental load. The larger the products, the less fit in a truck or in other ways of transport.

- **Percentage repair/sort of repair**

Some products will need repair after dismantling before they can be reused in a new building. There are two reasons: the product cannot fulfill its function anymore or the appearance of the product is not satisfying anymore.

Concrete hollow core slabs of XX illustrate the first reason: they cannot function anymore if the concrete coat is damaged and the reinforcing steel is exposed to the elements. The concrete coat has to be repaired before reuse. The second reason will occur more often, especially when building products are visible for the user. A good example from XX is the wooden stairs. The stairs must be repainted before reuse. Repair needs material and energy, which causes costs and environmental load.

- **Remaining lifespan**

The lifespan of a product depends on external aspects like climate, its use, and environment, and on inherent aspects like material qualities, design details and quality of the building process [Huffmeijer 1995]. For any reuse of a product, it is essential to know its remaining lifespan.

If we look at office XX, we see that many building products last much longer than the 20-year lifecycle of the building. For example: concrete elements: 75 years, aluminum gutter: 25 years, wooden floor elements filled with sand: 75 years, wooden columns 75 years, spine window frames: 40 years [Huffmeijer 1995]. It is hard to find a building part that will last for only 20 years in office XX. To conclude: the building will not collapse after 20 years, but it can be dismantled and most building products could be part of a new office, excluding the aluminum gutter that has a short remaining lifespan (5 years).

Another mechanism we have to take into account is the dependency of the lifespan of the product on the lifecycle of the building. If a building product lasts for 18 years, it is plausible that this product will not be replaced before the building is demolished after 20 years. The product will be repaired, or accepted in an inferior condition until the building is demolished.

- **Reliability**

Besides a shorter remaining lifetime, an older product also has a greater risk of failure. The risk of failure is assumed to be normal distributed and the standard deviation is one sixth of the average lifespan [Huffmeijer1995]. Suppose this is true, table 3 shows us the results of three building products of XX: the cumulative chance on failure and replacement in the first lifecycle of the building (0-20 years) and in the first and second lifecycle of the building (0-40 years).

Table 3 confirms the idea that it is not wise to reuse the aluminum gutter. But more surprisingly, the chance of failure of the window frames is also high: 50 %. That is easy to explain: if a lifespan of a product is normally distributed, half of the products has a lifespan shorter than the average of 40 years, the other half has a lifespan more than 40 years. Of course, if the window frames are maintained, more than 50 percent will last the required 40 years. This way of calculating is inaccurate, using the standard deviation of one sixth of the average lifespan. It is better for the final model of BELCANTO to use a more refined method; but as an approximation this calculation is nevertheless illustrative.

Table 3: Chance of failure for tree building products of XX

	life cycle of building	average lifespan of product ($\underline{x}$)	standard deviation (1/6* $\underline{x}$)	Cumulative chance of failure in first lifecycle building P(x < 20)	cumulative chance of failure in first **and** second lifecycle building P(x < 40)
aluminum gutter	20	25	4,17	0,11507	0,99984
spine window frames	20	40	6,67	0,00135	0,50000
concrete element	20	75	12,50	0,00001	0,00256

- **Out-dated products**

Some products will be of no use in the future. A good example is single pane glass. Nowadays, it is not allowed anymore, and only double-glazing is applied. If this trend continues, even double-glazing may not be sufficient in the future. Similar problems occur with installation products. All products that have a function in the energy balance of a building (installation and insulation) have a reasonable chance of becoming outdated sooner or later.

The threefold-glazing of office XX anticipates on future demands for energy use. Among other things, these threefold-glazing create a low energy need because of the high thermal isolation. Therefore this building part will not be out-dated in the near future.

- **Quantity**

In office XX, 84 window frames of the same size are used on the ground floor. A possibility is to reuse these windows again in an office or other large building. However the window frames are rather large (2 x 2.5 m.), it is also possible to reuse these 84 same window-frames in a housing project and use two or three windows at the ground floor of each house.

The quantity of equal building products will influence the reusability. The larger the number, the more chance there is on reuse in a new building. Nowadays, a building with different sizes of window frames will not be accepted, but in the future this may be the case, when raw materials become scarce.

- **Economical profit**

Until now we have only talked about costs, but reusing a building product brings also something in return. If we build an office in 20 years, we can reuse the product that is used for the first 20 years, and there will be no need to buy a new product.

Of course we cannot know at this moment the value of a product that will be bought in the year 2020. To find the economical value of the new product, and thus the environmental profit of the now used product, we relate the economical profit to the price of a product bought now, possibly proportionally decreased with the already used lifetime. In later research we will pay more attention to this aspect.

- **Environmental profit**

The same story is valid for the environmental profit. With LCA we can calculate the environmental load of the product. If we use this product again in the year 2020, we don't have to make a new product and therefore save materials and energy and diminish the environmental load. Of course, one can discuss if this is a right starting-point, because one should calculate with the environmental value of a product that will replace the old one in twenty years. Besides, if energy is saved with a new product, we can say that using the old product causes also an environmental loss. But, although this would be the most honorable way, it is not realistic. It is not possible to look in the future for such detailed information. Therefore we suggest to relate the environmental profit to the environmental value of the product now used in a building. This also will be discussed in later research.

4.2 Recycling of materials

Recycling of materials involves fewer demands in comparison with reuse of products as described above. Furthermore, connections between materials are now more important than the connections between products. An example: products that are connected in a fixed way can be recycled without problems when the products and the connection are made of the same material.

Table 4 gives an overview of the product features that influence the recyclability of building products. Because we described many product features before in the ELS 'reuse of products', we will concentrate on the product features that are different: connection to other materials, quality of the material, recycling process, and the quality of the recycled material.

- **Connection to other materials**

The fixed connections between the concrete hollow core slabs of XX, what caused problems for the reuse of the product, are for recycling of the material no problem: The concrete can be demolished and reused for road subbases. The window frames that are connected with a slat, will be damaged when the window frames are disconnected. When we look at reusing the material on a low level, as chipwood, the damaging will cause no problems, but if we want to reuse the beams of the window frames, the material damage obstructs the recycling.

The connection between materials can be categorized in the same way as described earlier in this article.

Table 4: Product features that influence life cycle costs, environmental load, and recyclebility for the end of life scenario 'recycling materials'

ELS	**INPUT BELCANTO**	**OUTPUT BELCANTO**		
Recycling of material	**Product features**	**LCC (guilder)**	**LCA (ecopoints)**	**Recyclebility (qualitative)**
Demolition/ Dismantling	• connection to other materials	dismantling costs	energy costs, emissions	ease of dismantling
	• ergonomics and safety	-	-	working conditions dismantling
	• quality of the material, recycling possible?	costs each kg	ecopoints each kg	-
Transport	• volume and weight	transport costs	ecopoints for transport	-
Cleaning	• connection to other materials	pollution and thus costs for cleaning material	-	-
Recycling	• recycling process	costs for recycling process	ecopoints for energy costs, pollution	-
	• quality of recycled material	devaluation of material in price	environmental loss	-
	• economical profit	saving costs not using new material	-	-
	• environmental profit	-	less load on the environment not using new material	-
Sum		**total costs recycling of materials**	**total environmental load recycling of materials**	**qualitative judgement recyclebility of materials**

- **Quality of the material**

Since window frames can be recycled in two ways - reusing the beams (parts) and reusing the reduced wood in chipwood - the quality of the wood after 20 years use determines the way of recycling. If the beams are rotten, only the last possibility remains. The quality of the material is not only determined by aging but also by pollution. In case of reusing recycled concrete aggregates for new concrete, e.g. remains of wood and gypsum may potentially deteriorate concrete quality. Steel recycling is effected less by pollution, since most of the pollution here (e.g. paint) will be removed in the recycling process.

- **Recycling process**

The recycling process also influences life cycle costs and environmental load. For some materials, like wood, there are more possible ways of recycling. Other materials can be recycled in just one way; for example, concrete can only be recycled as aggregate and used in roads or new concrete, saving in both cases gravel.

- **Quality of the recycled material**

Some materials may be recycled over and over without a significant quality loss, e.g. steel, while others may be recycled only once, or a few times at most, e.g. plastics. In some cases 100 % of recycled material is reused in the new material, in other cases only smaller percentages may be applied.

4.3 Landfill and Incineration

There are only a few product features that influence the output of BELCANTO (Table 5). The most important feature is the used material for the product. If it is combustible it can be dumped on a landfill or it can be incinerated. If it is not combustible only landfill is an option. But the sort of material influences the output of BELCANTO also in another way, some materials are extremely hazardous for the environment when they are burnt, like PVC, or dumped, like lead.

Table 5: Influence of product features on landfill and incineration

ELS	**INPUT BELCANTO**	**OUTPUT BELCANTO**		
Landfill/ Incineration	**Product features**	**LCC (guilder)**	**LCA (ecopoints)**	**Possibility of dumping, incineration (qualitative)**
Demolition/ Dismantling	• type of material combustable or not combustable	costs for seperation	energy needed and emissions released	-
Transport	• volume and weight	transport costs	ecopoints for transport	-
Landfill/ Incineration	• volume and weight	costs for landfill, incineration	environmental costs for landfill or incineration	-
	• type of material	costs for landfill, incineration	environmental costs for landfill or incineration	risk for health of people
	• economical profit	generation of energy in case of incineration	-	-
	• environmental profit	-	generation of energy in case of incineration, emissions in both cases	-
Sum		**total costs landfill or incineration**	**total environmental load landfill or incineration**	**qualitative judgement incineration, landfill of materials**

5 Conclusion

A case study, like office XX, helped us to describe all the product features that influence the output of BELCANTO; environmental load, life cycle costs and the suitability for a certain ELS. It was indeed a good choice to choose XX for its dismantability, because only a few products can not be reused a second time, and it was in this way possible to look at different scenarios of the end of life of a building

XX is designed to be dismantled after 20 years and this is indeed possible. The attempt to gear the lifespan of products to the life cycle of the office is less successful; most building products that are used have a lifespan that is much longer than 20 years.

Although we described in this article the important product features carefully, there are still some product features that have to be examined more in detail, like environmental and economic profit.

6 References

Guequierre, N.M.J., Ch.F. Hendriks, J. Kristinsson (1998) BELCANTO, an end of life cycle analyse tool for buildings. *Proceedings of the Second international workshop on reuse*, March 1999, Eindhoven, the Netherlands, not published yet.

Huffmeijer, F.J.M. en A.A.J. Damen (1995) Lifespan of building products: experienced data. SBR-publication 355, Stichting Bouwresearch, Rotterdam, the Netherlands. In Dutch.

Timmermans A.W.C. (1985) Means of Attachements. Delftse Universitaire Pers, Delft, the Netherlands. In Dutch

Knapen, M., D. Anink, J. Mak (1998) Enivronmental load of office XX compared with a reference office, W|E advisors, Gouda, the Netherlands. In Dutch.

Reinhardt, H.W., J.J.B.J.J. Bouvy, Proceedings of the international symposium, Rotterdam, The Netherlands, May 30-31, 1985, Delft University Press, Delft

Congress Industrial Flexible and Demountable building, The Hague, November 17th, 1998

195 THE ENVIRONMENTAL IMPACT OF INSULATION

N.A. Hendriks and J. de Hoog

Eindhoven University of Technology, Eindhoven, The Netherlands

Abstract

The use of thicker insulation material, e.g. in exterior wall constructions will result in a higher environmental impact during the production phase of a building life cycle. However, a higher thermal resistance means less energy consumption during the operational life span of the building. This decreases the environmental impact of the energy production (natural gas or oil). The result is an environmentally optimal thickness (EOT). Principally speaking, this EOT will be different for every insulation material, depending on the ruling environmental effect. It was found that the resulting functions of the total effect-thickness relations are rather "flat" near the optimum. This means that economics also play an important role when determining the environmentally optimal thickness. Furthermore the performance of the insulation materials in their application must be taken into account.

Results of a comparative research study are given in the paper.

Keywords: energy consumption, environmentally optimal thickness, insulation, polyurethane foam, mineral wool, insulation performance, LCA.

1 Introduction

The LCA methodology that was used for this study was developed by CML (Center for Environment, Leiden, The Netherlands) and currently runs on the computer program SimaPro, developed by Pré Consultants (Amersfoort, The Netherlands).

The environmental classes used in the CML method are: eutrophication, ozone

Durability of Building Materials and Components 8 (Volume Three). *Edited by M.A. Lacasse and D.J. Vanier*. Published in 1999 by NRC Research Press, Ottawa ON K1A 0R6, Canada. ISBN 0-660-17742-0

depletion potential, ecotoxicity (aquatic), ecotoxicity (terrestrial), energy consumption, greenhouse effect, acidification, solid emissions (waste), summer smog, human toxicity and exhaustion of earth's resources.

Life cycle assessment of building components is a relatively young science. This means quite a few aspects (e.g. allocation methods, system bounderies) have not been (internationally) standardized. As a result of this lack of standardization, several studies can not be easily compared. Another problem is the enormous discrepancy in process data, used for LCA calculations. Therefore results of studies and conclusions must merely be considered as indications. This is also true for the information in this paper.

LCA is the scientific method used to determine the environmental impact of different products, processes and waste scenarios. The method is based on the fact that all the relevant (production) processes use (raw) materials and energy and produce emissions and waste.

But it is of course impossible to compare the literally thousand different emissions from, for instance, two different production processes. Therefore, so called environmental classes are introduced and computer programs have been developed to cope with his huge amount of calculations that have to be done.

In this paper the results of LCA calculations of some insulation materials are given. The study takes into account the production phase and the waste scenarios, as well as the effect of thicker insulation to energy conservation.

2 Previous work

Several attempts have been made to develop a consistent LCA method. Most of this work can be classified as case studies. More general publications were produced by Guinée et al [1992] and Kortman et al [1994].

At the moment an ambitious project is being undertaken by IVAM Amsterdam, TNO-MEP, Intron and the Eindhoven University of Technology to reach a general agreement on how to perform LCA studies following a standardised format. This standard format will be used in the MOLCA project (Model for Office Life Cycle Assessment). With this model it must be possible to assess the environmental impact of complete office buildings. Introductionary studies have been done by Hendriks and De Hoog [1998, 1998].

3 Classification and normalisation

The core of a LCA study consists of two steps: classification and normalisation.

The classification step is necessary to allocate a certain emission to the right environmental category. For example, CO_2 emission contributes to the greenhouse effect, which means that in the classification step CO_2 is allocated there. But CH_4 (methane gas or mining gas) for instance also contributes to the greenhouse effect, even eleven times stronger than CO_2. To solve this problem the individual classification factors of many substances have to be defined. This has been done (mostly by CML) for many substances in every environmental category, as mentioned in the introduction. Many substances contribute to more than one environmental class. Finally it must be mentioned that the actual classification factor of a certain substance also can depend on the way it is being emitted. For example the classification of cadmium in the category human toxicity is 580 airborne and 2.9 waterborne.

In the normalisation step of the LCA, environmental impacts are related to the average contribution of each individual inhabitant in a certain region. This region could be the whole world, one country or a continent like Europe. The normalised effect score is obtained by dividing the actual effect score (in kg) by the yearly emission per inhabitant ($kg.yr^{-1}$).

In case of comparison normalised effect scores must be used with great care because all sorts of different sets of normalisation factors may be used. The CML method currently uses whole world normalisation scores.

4 Effect of insulation

A common misunderstanding is that energy consumption depends linearly on the thickness of the insulation. In reality the relation between thermal resistance (Rm-value) and energy consumption is not linear. This is caused by the transmission losses being proportional to the U-value, which is reciprocal to the Rm-value. This is shown in Figure 1.

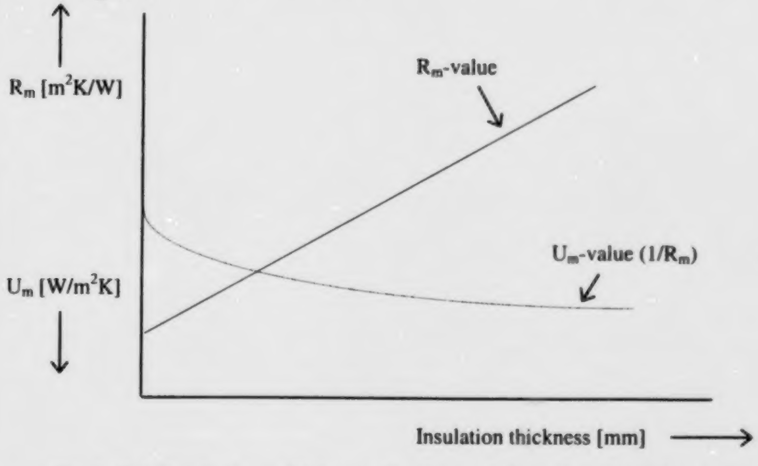


Fig. 1: Relation between thickness, U-value and Rm-value of insulation material

Figure 1 shows that with increasing insulation thickness the U-value decreases less and less. This means that also the saving on energy consumption becomes less meaningful. The result is that eventually the saving on environmental pollution (because of less energy consumption) with increasing insulation thickness hardly increases. In other words: the total sum of the environmental pollution caused by the production of insulation and by the energy production/consumption must reach a minimum somewhere. "Somewhere" means: at a certain insulation thickness. This thickness is called the Environmentally Optimal Thickness (EOT).

Several studies [Hendriks, 1998] have been made to determine the EOT for established insulation materials such as polyurethane foam (PUR), expanded polystyrene (EPS) and mineral wool (MWR).

These studies show that for each material there is a "ruling environmental effect".

5 Cumulated environmental impact

Figure 2 gives the results for polyurethane foam for the environmental effect "human toxicity". The used waste scenario is 10% landfill and 90% incineration without energy recovery. If energy recovery is taken into account the equilibrium lies around a thermal resistance $R_m = 6.5$. The relation with the EOT is given with

$$R_m = \frac{d}{\lambda},$$

where d = thickness and

8 = coëfficient of thermal conductivity

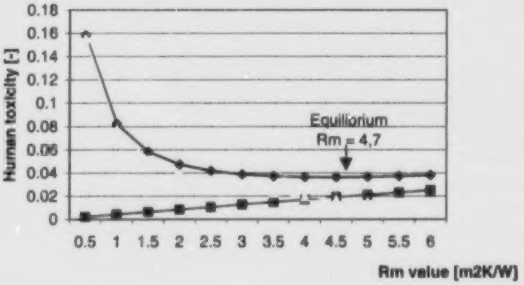


Fig. 2: Cumulated environmental impact of polyurethane foam (PUR) (Application in facade construction)

Depending on the assumed lifetime of the building (25 years or 50 years) the EOT, related to the thermal resistance (Rm) varies from about 4.25 m^2K/W to about 6 m^2K/W.

For mineral wool this is given in figure 3. This result is based on a waste scenario of 90% mechanical recycling.

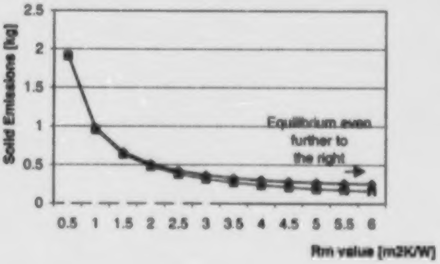


Fig. 3: Cumulated environmental impact of mineral wool (MWR, with recycling) (Application in facade construction)

Here the ruling environmental effect is solid emissions. As already mentioned for polyurethane foam the effect of recycling is substantial. In the case of polyurethane foam the recycling refers to incineration with energy recovery. For mineral wool recycling means mechanical recycling. There are only very few producers using this technology. If standard process data for mineral wool are used, this means a waste scenario without recycling, the equilibrium thermal resistance is much lower. This is shown in Figure 4.

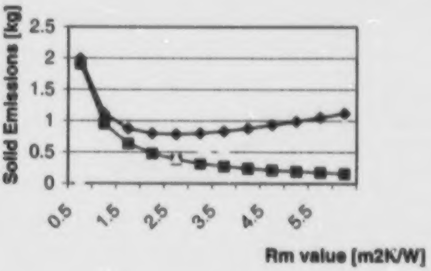


Fig. 4: Cumulated environmental impact of mineral wool (without recycling)

6 Environmentally Optimal Thickness (EOT)

Both figure 2 and 3 show that the graph for the total sum of environmental effect is very "flat" left and right from the EOT. This means that from an economical point of view it is not very interesting to try to reach the EOT. It seems that an R-value of 3.5 to 4.0 may be the optimal economical and ecological value; if we assume a proper recycling scenario. This means that with respect to the thermal resistance the choice of type of insulation material is quite irrelevant. The actual EOT then is only dependent on the coefficient of thermal conductivity (8-value) of the insulation material. That means that the EOT for polyurethane foam (8= 0,026 W m^{-1} k^{-1}) is about 90 mm and for mineral wool, (8=0,040) about 140 mm.

7 Conclusions

1. At first instance the increase of insulation thickness will lead to a decrease of the environmental pollution. However this effect becomes less and less with increasing thickness. An environmentally optimal thickness can be determined.
2. The environmentally optimal thermal resistance is strongly dependent on the waste scenario.
3. The economically and environmentally optimal thermal resistance is hardly dependent on the choice of insulation material and lies between 3.5 and 4.5 m^2K/W, depending on the expected life time of the building.
4. Provided that a proper recycling scenario is available the economically and environmentally optimal thickness for polyurethane foam and mineral wool, as applied in a facade construction is about 90 mm and 140 mm respectively.

8 References

Guinée J.B. et al (1992) "Milieugerichte levenscyclusanalyses van producten. Deel I: handleiding. Deel II: achtergronden", NOH rapport (in Dutch) 9253/54.

Hendriks, N.A. and J. de Hoog (1998) "The Importance of Recycling in Life Cycle Assessment of Roof Systems", Proceedings of the 10th IWA Congress, p. 93-111, Copenhagen.

Hendriks, N.A. and J. de Hoog (1998) "Important factors to the sustainability of flat roofing systems", paper presented at the IFD Congress in Amsterdam, October.

Kortman, J.G.M., Lindeijer, E.W. et al (1994) "Towards a single indicator for emissions - An exercise in aggregating environmental effects', IDES, CE, Informplan.

Hendriks, N.A. (1998) "DuBoboekje- Opstalan"(in Dutch), Oisterwijk.

196 TENETS OF SUSTAINABLE ROOFING

T.W. Hutchinson[1] and K. Roberts[2]

[1]Legat Architects, Chicago, IL, USA, [2]Glanville Consultants,
Abingdon, UK

Abstract

There is a genuine interest among enlightened building owners and roof system designers in adopting environmental objectives. In many countries a whole generation has grown up in a culture sympathetic and supportive to 'green' issues and many colleges and universities include environmental studies as part of their normal course work. The challenge facing the roofing industry and the CIBW.83/RILEM 166 RMS Committee, of which the authors are co-chairman is to translate this interest and good will into practical guidelines which will lead to improvements in the long term performance of roofs, within a given financial budget.

Defining Sustainable Roofing as: "A roof system that is designed, constructed, maintained, rehabilitated and demolished with an emphasis throughout its life cycle on using natural resources efficiently and preserving the global environment," this paper addresses life cycle analysis issues across each step in the life of a product: from raw material extraction or processing, production, packaging, transportation, design, installation, service life, reuse, recover or tear-off, and its ultimate disposal and is illustrated in a cradle to grave model.

Practical guidelines or 'tenets for sustainable roof systems' are developed and systemized under the basic principles of 'Minimizing the Burden on the Environment,' 'Conserving Energy,' and 'Extending Roof Lifespan.' These tenets are produced in a form that will be of practical everyday use for designers, suppliers, and contractors. Examples of sustainable roof design from around the world with optimal service life goals are given.

Keywords: durability, life cycle analysis, sustainable development, sustainable roof system design, sustainable roofing

Durability of Building Materials and Components 8 (Volume Three). *Edited by M.A. Lacasse and D.J. Vanier*. Published in 1999 by NRC Research Press, Ottawa ON K1A 0R6, Canada. ISBN 0-660-17742-0

1 Introduction

The International Conference on Climate Change held during 1997 in Kyoto, challenged governments to improve on their national environmental performance in terms of reducing both pollution and energy demand. To work towards these desirable goals, the concept of 'sustainable development' is being actively promoted in the construction and property industries in some countries.

There is a genuine interest among enlightened building owners and specifiers in adopting environmental objectives, as has been found from the numbers of enquiries arising from articles published in specifier magazines. This has been recognized by a few manufacturers who now promote their products' green attributes in marketing campaigns. In many countries, a young generation has grown up in a culture sympathetic to 'green' issues, and today many colleges and universities include environmental studies as part of their normal coursework.

The challenge facing the roofing industry is to translate this interest and goodwill into practical guidelines, which will lead to improvements in the long term performance of roofs, within a given financial budget. The purpose of this paper is to educate the roofing industry in regards to sustainable roofing, and to identify the underlying principles, or tenets, and thus offer practical guidelines.

2 Background to the work of CIB/RILEM

The CIB W.83/RILEM 166 RMS Joint Committee on Roofing Materials and Systems is a voluntary and independent group of recognized experts and roofing specialists from almost 20 countries, who meet on average once a year to exchange results and findings of international research and studies into low slope membrane roofing. The committees are set up for fixed five year periods, during which a specific and relevant topic is examined by a Task Group.

The CIB is the International Council for Building Research Studies and Documentation, and the RILEM is the International Union of Testing and Research Laboratories for Material and Structures.

Task Group 2 first met in Brussels in May, 1996, and was established to examine the issue of sustainable roofing. The scope of the work is to "determine the current state-of-the-art of design, application and maintenance practices throughout the world in the field of environmentally-friendly low-sloped flexible membrane roofing systems, and to publish a Final Report during the year 2000."

This paper expresses the views of the co-chairmen, which is a recapitulation of the committee's three years of work. It is hoped that by bringing the work of the Task Group to a wider audience and seeking a broader input, then the Final Report will carry greater authority as we work towards adopting more sustainable roofing systems in the twenty-first century.

3 Current views of specifiers

Until a few years ago, the term 'sustainability' was not part of the vocabulary of an architect or engineer. Today, however, it is one of the more important concepts in the design process. A recent survey of American architects and engineers revealed that, while 60% of the respondents consider that sustainability and environmental issues are important, only 35% understand the concept of sustainability and even fewer can define it. (Hutchinson and Roberts 1998)

An architect is often involved from the early conception of a project and later through all its phases of development. Sustainability should be accounted for over the entire lifespan of the building, and this whole-system-thinking stresses the importance of inter-relationships, consequences and feed-back loops. It is a process which manifests itself in the sum of its parts rather than the individual components. However, the search of literature available to specifiers has found that most of the documents produced are product based, which contradicts the whole system approach in considering the long-term performance of all of the components combined.

There is a belief amongst some specifiers that sustainable development can be compatible with economic growth. For example, in many countries, the increased costs of disposing of waste in landfill sites is providing a real incentive to reduce the volumes of bulk waste produced.

Expecting designers to undertake a separate environmental audit is considered to be unrealistic. If another design procedure or 'paper exercise' were to be imposed, similar to the introduction of a rigorous quality procedure, then the industry could become over-burdened with paperwork, losing sight of the real issues and ultimately becoming counter-productive. At best, it is to be hoped that designers keep in mind the key issues, which are often no more than common sense and best practice.

Today in many countries, the topic of sustainability is not high on the agenda. Instead, it is economics that remains the key issue with the lowest cost being the principal factor in design decisions.

4 Definitions of sustainability

Constructing a definition of 'sustainability' that can transcend languages is difficult. In 1987, the Brundtland Report was presented to the United Nations Commission on the Environment and Development and it defined ***'sustainable development'*** as:

> *"Development that meets the needs of the present without compromising the ability of future generations to meet their own needs."* (Anon 1997)

Later in 1994, the First International Conference on Sustainable Construction was held in Florida, USA, where the attendees defined the term ***'sustainable construction'*** as:

> *"The creation and maintenance of a healthy built environment based on ecologically sound principles and resource efficiency."* (Anon 1997)

The Task Group has looked at the roofing element of a building and after considerable discussion, it was thought that the following definition used in the introduction of the "Proceedings of the Sustainable Low-Slope Roofing Workshop" (Desjarlais 1996) held at the Oak Ridge National Laboratory in the USA in October 1996, offered a good working definition of what is currently understood to be a ***'sustainable roof'***:

> *"A roofing system that is designed, constructed, maintained, rehabilitated and demolished with an emphasis throughout its life cycle on using natural resources efficiently and preserving the global environment."*

These concepts are difficult, not only to implement but to comprehend. Their value lies in their far reaching scope. Sustainable development supposes that construction methods and their relationship with the environment, life cycle analysis and environmental quality must all be taken into account. Consequently, it is an all-encompassing concept that provides a stable framework for new design methods. Put simply, it is about taking 'the long view.'

Life cycle analysis involves an examination of each step in the life of matter: from raw material extraction or processing; production; packaging; transportation; design; installation; service life; reuse, recover or tear-off; and ultimately disposal. This is typically illustrated in a 'Cradle-to-Grave' model.

At each stage (of the model) various environmental attributes can be defined in terms of energy demand, CO_2 emission, types and quantities of pollutants, volume of waste, and other parameters. The final 'score' is related to the number of years service that the roof gives, which will not be known at the design stage, but can be no more than a best estimate based on published data, assuming good standards of workmanship and maintenance. Another difficulty is in weighting the various environmental data. This raises questions such as: How important is it to reduce CO_2 emissions? What is the impact of transportation? What types of pollutants are hazardous and in what concentrations do they become harmful to health?

5 The complexity of the problem

In assessing the environmental performance of a roofing system at a building design stage, it is important to take a holistic approach and to consider the whole picture. Studies are underway assessing the life costing of a construction product in terms of its embodied energy, CO_2 emissions and other parameters. One such initiative is the BREEAM project in the U.K. (Krogh et al. 1997). In Denmark, a report has been produced, which seeks to identify which parameters are important for environmental assessments and a start has been made collecting standard data. The Task Group is aware of other initiatives, and is keen to learn of their progress so that lessons can be learnt for benefit of the whole.

One of the difficulties faced by this type of exercise is that the available information is largely product data from laboratory testing. In the real world, the standards of workmanship in assembling the individual components are not perfect, and the subsequent long-term maintenance is often poor. Concerns about the manufacture of one component of a roof system are only a small part of the whole picture when the in-service performance and ultimate replacement of the roof is considered.

It is recognized that once built, a building and its roof will have a life of its own. As properties are bought and sold, the occupants change; altering, extending or rebuilding to suit their own individual needs and in a manner that cannot be predicted. This was well illustrated by Stewart Brand in his book entitled 'How Buildings Learn: What happens to them after they're built' (Brand 1994). This unknown future adds another variable to be assessed at the design stage.

Sometimes what may be good environmental advice for one country or region, may not be appropriate in a neighboring district. For example, in France the risk of flooding to low lying urban areas near the banks of major rivers caused by widespread development is a concern. A municipal directive has been issued that all new buildings should store rainwater on their flat roofs, thus reducing the rate of stormwater run-off into the underground drains and rivers. This trend to slow down rainwater run-off from roofs is contrary to trends in other countries, which are to increase roof slope and improve drainage. (Chaize 1995)

While environmental studies and debates have laudable goals, it is basic practical advice on sustainable development that is sought by designers and contractors alike. The Task Group has identified three key areas where improvements could be identified:

- ***to minimize the burden on the environment***, being responsible stewards of the earth's resources.
- ***to conserve energy***, recognizing savings by improving thermal efficiency of roofs.
- ***to prolong the life of roofs***.

6 The 'Tenets of sustainable roofing'

Arising from discussions within the Task Group it was suggested that it would be helpful to draft a summary of what appears to be best practice for sustainable roofing, based on published reports, technical papers and the experience of the members. It is considered important that this summary should be in a form, which would be of practical everyday use for designers, suppliers and contractors alike, ideally on one page and widely circulated.

These basic principles or 'tenets' of sustainable roofing have been brought together by the Task Group. The second draft for public comment is given in Figure 1. These tenets are applicable to membrane roofing systems on permanent buildings and have been broadly grouped under three sub-headings: minimizing the burden on the environment; conserving energy; and extending the life of a roof.

TENETS OF SUSTAINABLE ROOFING

MINIMIZE THE BURDEN ON THE ENVIRONMENT

1a. Use recycled or recyclable products wherever logical.
1b. Consider the use of products made from raw materials whose extraction is not damaging to the environment, and are thus less invasive.
Adopt systems and working practices that reduce materials wastage.
Select products that minimize health risks during the life of the roof.
Avoid products that are disposed of in hazardous waste tips.
Recognize regional climatic and geographical factors, such as the control of rainwater disposal.
Promote the use of 'green roofs' supporting vegetation, especially on city centre roofs.

CONSERVE ENERGY

Optimize the real thermal performance, recognizing that over the lifetime of a building thermal insulation can greatly reduce heating or cooling costs.
Keep the thermal insulation dry, to maintain thermal performance and improve durability of the roof.
9a. Use local labor, materials and services wherever practical to reduce transportation.
9b. Recognize that embodied energy calculations are a useful tool for comparing alternative constructions.
9c. Consider the roof surfacing, texture and color with regard to geographical location and affect on energy performance.

EXTEND ROOF LIFESPAN

10. Adopt a responsible approach to design, recognizing the value of the robust roof.
2. Employ designers, suppliers and contractors who are adequately trained and have appropriate skills.
3. Provide positive drainage to reduce long-term ponding.
4. Minimize the number of service penetrations or holes through the roof.
5. Adopt prefabricated components, if they simplify site assembly.
6. Inspect roofing works in progress, using appropriate quality systems and take corrective action as necessary.
7. Control access onto completed roofs to reduce puncture damage, providing defined walkways and temporary protection.
8. Adopt preventative maintenance, with periodic inspection and timely repairs.
9. Consider ballasted or mechanically fixed roof systems, to ease the sorting and salvage of materials at the end of the life of the roof.

Fig. 1:Tenets of sustainable roofing

These tenets are applicable to membrane roofing systems on permanent buildings and are not fixed and irrevocable. It is expected that as our understanding develops of how roofs perform and how they affect the global environment, then the tenets would also evolve. It is important that the summary is kept short, to no more than one page, otherwise the busy designer will not use it. A final report will be published in October, 2000.

On their own, each tenet could be considered to be over simplistic and no more than common sense. However, when they are considered as a whole, they make a contribution to promoting good practice in the design, construction and maintenance of membrane roofing systems.

The exercise is also beneficial in helping to focus future development on relevant issues. For example, in the U.K., there is a general lack of awareness of the fact that entrapped water affects the thermal performance of most common insulations. By highlighting this fact, attention can be given to improving site practice and maintenance, ultimately resulting in a reduction in the heat loss through the roof and long-term savings of energy.

7 Tenet substantiation

It is important that these tenets are based upon accredited work and sound principles. Figure 2 contains an example of a written justification for one of the individual tenets and refer to published texts. It may be that there are further tenets to add to the list or, alternatively, there may be some that do not deserve inclusion in the final draft. From the discussions both before and during this Congress, this list of 'tenets of sustainable roofing' will be updated and circulated to those who express an interest in the topic.

8 Examples

Classic examples of sustainable roofing began millenniums ago. Thatch, slate, and stone shingle tile all exemplify many of the tenets of sustainable roofing. Modern day examples are present as well. Legat Architects in Chicago, Illinois, takes into consideration all the tenets when designing roof systems, minimum R values, and 20 year service lives are company goals. Educating clients into the benefits of sustainable roofs has proven helpful and creates a mutual trust and gain (See Figure 3a, b, c and Figure 4).

Tenet: **No.12**

Tenet: Provide positive drainage to reduce long term ponding.

Why Should this Tenet be Included: An area where designers and contractors alike can contribute to improving the environmental impact is to build and maintain roofs to have a long service life.

Extending the lifespan of a roof is desirable from the environmental perspective as it results in a better use of raw materials and reduces the volume of bulk waste ultimately to be dumped in landfill sites.

Roof systems that have positive drainage last longer than those with long term ponding. Removing the water from the roof surface as quickly as possible has a multitude of benefits: eliminates the buildings of debris and affluents in the ponding water, material that could attach the membrane, should leaks arise, the amount of water infiltration is minimized, the potential for bacteria growth is minimized or eliminated and promotes good roof system design.

A totally flat membrane roof relies on a perfect standard of workmanship and regular active maintenance to keep it watertight. In the real world this rarely happens. In the interests of building roofs that last longer giving economic benefits to the building owner and environmental benefits to all, it is good practice to adopt positive roof drainage wherever possible.

References

FRCAB Information Sheet No 27, Improving Falls on Existing Roofing. May 1997

BS 6229: 1982 (1995) Code of practice for flat roofs with continuously supported coverings

RCI Technical Note No 60. 'Sustainable Roofing: An Introduction,' July/August 1997

Fig. 2: Justification of Tenet 12

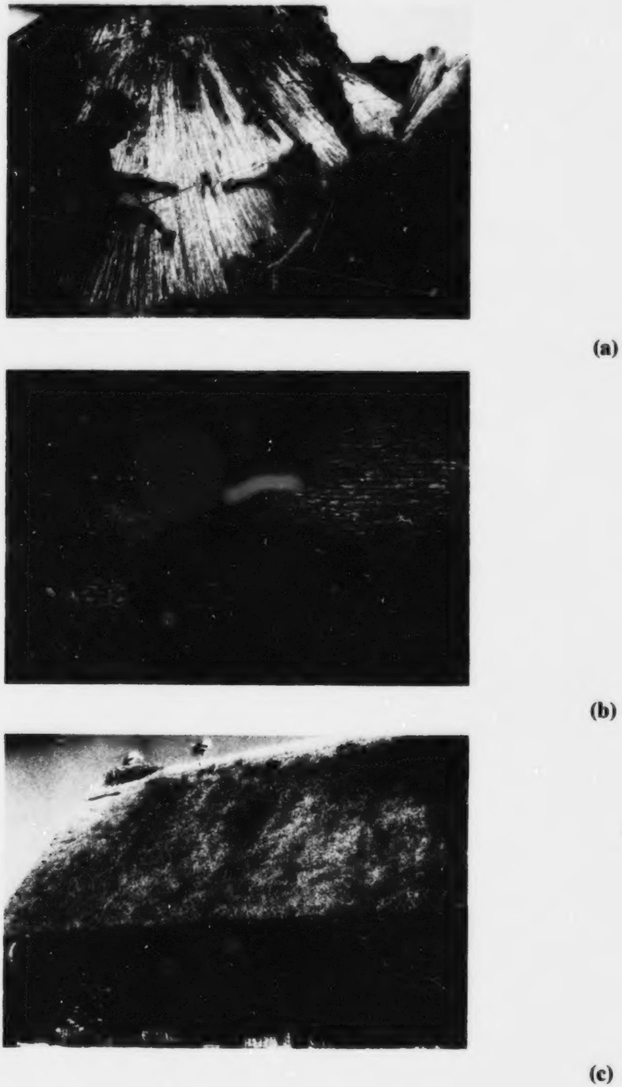


Fig. 3: Still in use today, thatch and stone shingle roof systems are historical examples of roof systems that embody many of the tenets of sustainable roofing

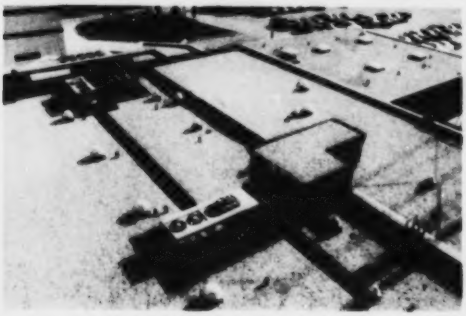


Fig. 4: Successful roof systems designed for twenty-year plus service lives in alignment with the tenets of sustainable roofing are currents being designed and constructed

9 Conclusion

As we enter the twenty-first century, the ideals of sustainable architecture will manifest themselves via codes, owner mandate and regulation. Obtaining a sustainable roof system can be achieved by adhering to the straight forward approach adopting tenets where possible. Construction techniques and materials will evolve, and with them the tenets of sustainable roofing and the concept of designing for the long term. Those who take an active role in this endeavor and embrace the concepts of sustainable roofing will be ready for the environmental challenges of the twenty-first century.

10 References

Allwinkle, S. (1994) *The Assessment of Life Span Characteristics and As-built Performance of Flat Roofing Systems, Summary and Recommendations for Construction Professionals*, Napier University, Edinburgh.

Anon, (1997) *CIB Co-ordinators' Trend Reports: An Anthology of Future Perspectives*, CIB Publication 211, Amsterdam.

Anon, (1996) *Sustainable Building in the Netherlands: National Package*, Dutch Ministry of Housing Spatial Planning and the Environment, The Hague.

Booth, R.J., and Kettenbeil, P.S. (1994) *Opportunities for Accelerating Implementation of Environmentally Sustainable High Performance Housing*, Canada Mortgage and Housing Corporation, Ontario.

Brand, S. (1994) How Building Learn: *What happens to them after they're built*, Viking, London.

Chaize, A. (1995) *Short Term Retention of Rainwaters: economic and ecological aspects of low slope roofs*, Proceedings from Ninth IWA Congress, Amsterdam.

Desjarlais, A. (1996) *Proceedings of the Sustainable Low-Slope Roofing Workshop*, Oak Ridge National Laboratory, USA.

Fricklas, R.L. (1997) *Roof Asset Management Survey*, Roof Consultants Institute Interface.

Hutchinson, T.W. and Roberts, K. (1999) *Working Towards Sustainable Roofing: An Interim Report from the CIB/RILEM Joint Committee on Roofing Materials and Systems*, Task Group 2, Proceedings from Tenth IWA Congress, Copenhagen.

Krogh, H., Hansen, K., and Hoffman, L. (1997) *Collection and Use of Environmental Data on Building Materials*, Danish Environmental Protection Agency, Copenhagen.

Roberts, K. (1995) *Working Towards Getting The Roof Right First Time*, Proceedings from Ninth IWA Congress, Amsterdam.

Roberts, K. (1997-98) *Sustainable Roofing 1-5*, Technical Notes published in Roofing Cladding and Insulation, London.

197 DESIGN FOR SUSTAINABLE BUILDINGS IN DEVELOPING COUNTRIES

A.R. Makenya[1] and G. Soronis[2]

[1]KTH-Royal Institute of Technology, and [2]Swedish Building Standards Institution, Stockolm, Sweden

Abstract

Durability of building materials, economy, functionality, aesthetics, health, ecology and social-cultural aspect can be considered as key factors in the design of sustainable housing. However, while these factors are being considered with vital importance during the design process in the industrialized countries, it has not always been the case in developing countries. There has been a tendency to over-look or underestimate these basic factors related to design of sustainable housing including the durability aspect of the building materials. The results have been associated with some undesired effects which do not meet the requirements for sustainability and service life of the building. In general, when it relates to housing provision issues in developing countries, it is the delivery aspect that is regarded as important and not, for instance, durability or quality. It is possible to change this mentality and adopt an effective approach whereby all the factors of sustainability are systematically analyzed and applied on design. One can also point out that a decent and a durable shelter in a wholesome environment is essential to human health and to human development. Additionally, it is worth mentioning that a durable and properly designed house contributes to the well-being of a society, from both economical and affordability points of view. Conclusively, there is great need for the developing countries as we enter the 21st century, to identify the problems and challenges to designing sustainable buildings. Priorities such as regulations, standards and codes of practice stressing all those design factors are needed to contribute to a design of sustainable buildings in the developing countries.

Keywords: Building materials, developing countries, sustainable building, sustainable design.

Durability of Building Materials and Components 8 (Volume Three). *Edited by M.A. Lacasse and D.J. Vanier*. Published in 1999 by NRC Research Press, Ottawa ON K1A 0R6, Canada. ISBN 0-660-17742-0

1 Introduction

As a priority and in order to meet the requirements for designing sustainable buildings towards the 21st century, there is a need for the developing countries to define their needs in a global perspective, while adopting approaches that can lead to practical, effective and local solutions (Makenya 1998).

In a similar argument that relates to a concept of sustainable building, the United Nations Centre for Human Settlements (UNCHS, Habitat Report 1986) puts more emphasis and mentions that, "human settlements are not simply housing or for that matter, merely the physical structure of a city, town or village but an integrated combination of all human activity processes including residence, work, education, health, culture, leisure etc.; and the physical structure that supports them".

A sustainable building approach in developing countries involves several factors. Mitchell and Bevan (1992) argues for example that, housing provision and the meeting of housing needs should not only be limited to increasing the number of housing units, but all the related issues which will result in providing sustainable housing. Another factor mentioned in the UNCHS (Habitat Report 1986) is the population growth increase problem, and it mentions that by the year 2000, eight out of ten people will be living in developing countries.

According to Haagenrud and Henriksen (1996), the deterioration of building materials and constructions attributes to the economic, cultural and environmental problem which is related to and affects the sustainable development of any society.

This paper discusses these issues and gives recommendations and proposals on how to solve problems concerning sustainable housing in developing countries.

2 Problem statement

The problem of designing for sustainability and sustainable housing are principally similar in almost all developing countries. These problems include lack of innovation in durable materials and systems used in residential construction. Consideration of the durability of building materials which should also be sustainable is not strictly demanded (CIB Coordinators' Report 1997).

Another existing problem, is the reluctance of local professionals and especially decision makers, to encourage the use of durable building materials (whether locally available or innovative) that are environmentally friendly (Makenya 1996).

Research performed by the Building Research Establishment (BRE 1982) on building failures in traditional housing showed that incidence of failure was attributed in 50% of cases to design faults, 40% to faults in construction on site, and only 10% to product faults.

A study in Brazil (Fernandez-Hachich and Thomaz 1996) elaborates that, "the housing industry particularly the social housing construction has a lot of problems, including the lack of quality assurance policies. And most of the local building regulations, standards and specifications were not sufficient to enable the evaluation of building materials and systems. This is mainly because most of them did not specify required levels of performance and durability. And even if they were enough, the government does not have actually a way to verify the conformity of the practises in building against the regulations or standards".

3 Sustainability

3.1 Defining sustainability

So far, it has been difficult to formulate a common definition for sustainability. In most countries in the world, sustainability is taken to mean more than environment, and usually involves economic and social sustainability. Nevertheless, Sarja (1998) gives a technical definition of sustainability as follows: "Sustainable building is technology and practice which meets the multiple requirements of the people and society in an optimal way during the life cycle of the building facility".

3.2 Designing for sustainability

Sustainability is constrained by the laws of nature including thermodynamics, chemistry and time. The concept of sustainable development (Kibert 1998) appears in the construction disciplines in various ways such as sustainable construction, ecologically sustainable development, green building, sustainable architecture and resource efficient construction.

Further, Kibert (1998) argues, if sustainability principles are to apply to industry, government, and the economy, it is evident that they must also be applicable to construction, an industry whose end-products consume a significant proportion of all materials and energy in their creation, operation and deconstruction.

4 Design for sustainable buildings: Related factors

4.1 Related factors

For a successful achievement in designing sustainable buildings, a number of factors or requirements are necessary and must be considered. In most cases these factors depend on each another. Sarja (1998) discusses the related factors or requirements of sustainability in details and one is discussed in brief by the authors of this paper. These include:

- *Economy*
- *Functionality*
- *Aesthetics*
- *Durability*
- *Ecology*
- *Health*
- *Social-cultural aspects*

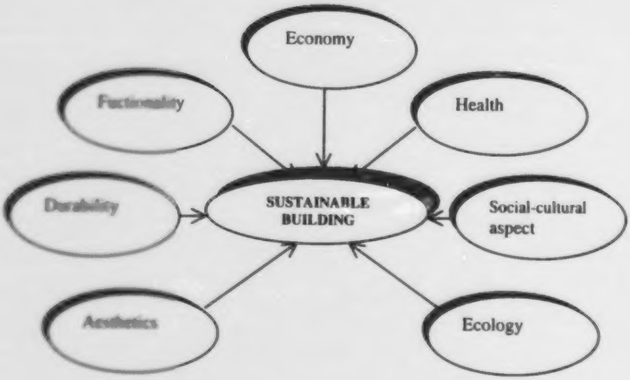


Fig. 1: Multiple requirements for designing sustainable buildings

4.1.1 Social-cultural aspect

The related (integrated) factors including, durability, economy, health, aesthetics, functionality, ecology have been discussed in length in many scientific reports and by various scientists, including Sarja (1998). However, in the past, the social-cultural aspect has not been discussed in detail. The reason is probably that in the last few decades, economies of many developing have not been able to support such issues (social-cultural) in their general technical development programs.

It can be argued that geographical position influences the social-cultural attitude of any society. From this fact, it is true that social and cultural attitudes differ from one geographical location to another, i.e. from north to south and likewise, from east to west. To integrate sustainability requirements for a developing country, it is necessary to include this requirement, i.e. the social-cultural aspect. This means that standards and codes of practise writers should emphasize technically simple and low cost design solutions which can easily be adopted to the social economic situation of those countries.

5 Priorities, proposals and challenges

5.1 Priorities

The priorities for research development in developing countries need to be based on those requirements as presented in Fig. 1. These need to be used as an important tool for designing sustainable buildings. Each country or local region will need to carry out research according to their interest and crucial demand, i.e. by prioritising the requirements. In some cases, it may be even possible to conduct parallel research activities, for example researching on economy and social-cultural aspect.

Regarding future research, existing research results from the industrialized countries can be analyzed, reviewed and developed for use in developing countries. However, according to Sarja (1998), new knowledge is needed including standards addressing the durability and service life of materials and structures in varying environments.

Future research should include the development of regulations, standards and codes of practices concerning the issue of sustainability in buildings. In most developing countries, standards and guides already exist; however, they need to be reviewed and updated, in order to meet the international standards (ISO) requirements. When acceptable, they can be integrated in the process of sustainable building design.

A paper by Soronis and Makenya (1998), discusses a proposed standard for sustainable building. This paper highlights the considerations regarding sustainability in building design. It further suggests that, this can be achieved through utilizing the principles of ISO 9000 series (quality management), ISO 14000 series (environmental management) and the current work within ISO/TC59/SC14 (Design Life). Sarja (1998) in a similar argument suggests that, before integrated life cycle design can be introduced, new standards and guides will be needed.

The working documents of ISO/ TC 59/SC14 (Design Life) for example, may be very useful references in future research work in developing countries where sustainable design is a concern. Within ISO/TC 59/SC14 a new work item has been initiated to include environmental performances in addition to traditional qualities for the design of buildings.

Other reference material which can be used for future research is presented in a paper by Lippiat (1998), on BEES (Building for Environmental and Economic Sustainability). The BEES software measures the environmental performance of building products by using the environmental life cycle assessment (LCA) approach specified in latest versions of ISO 14000 draft standard.

5.2 The challenges

Many discussions have been going on concerning the use of innovative approaches in the building materials and systems used for the design of a sustainable building. However, so far little has been achieved. This is partly because government policy and programs concerning housing issues in many developing countries still do not address sustainability (Makenya 1998).

Designers are in most cases reluctant to apply new design tools, like standards, probably because they are judged as complex. This is even the case in industrialised countries. A corresponding argument by Frohnsdorff and Martin (1996) discusses that service life predictions are unlikely to be accepted by designers in the US for routine use until standards and a computer-integrated knowledge system are in place. For this reason, active participation in the development process of material researchers dedicated to turning innovations, including new standards and guidelines, into new applications is critical.

The factors mentioned in the integrated life cycle design (Fig.1) are connected to the function and performance of the facilities (Sarja 1998). However, the overall decisive factor in any society or community is the micro and macro economy. This means that, problems have to be considered in both governmental and private budgets. The main criteria should be that budgets stay within the permissible limits, since they play a major role when decisions for selecting certain design alternatives are taken.

6 Concluding remarks

This paper has discussed problems and challenges concerning sustainable building design in developing countries. Towards the year 2000 and beyond, there is a great need for developing countries to put more emphasis on and identify their needs concerning, building sustainability, which includes the durability of building materials. As a proposal, desired results for sustainable building design can be achieved by putting more efforts on appropriate research projects and implementation, while strictly taking into consideration:

- The multiple requirements/ factors of sustainable building design (as in Fig. 1).
- Building standards (ISO standards) in the design process.
- Participation in international programs involving sustainable building.
- Establishing national or regional programs dealing with sustainable building.
- Reviewing or establishing regional standards (when necessary) which can accelerate or simplify standards implementation, but in close co-operation with the ISO to avoid duplication. (The Current European Standard (CEN) is an example).
- Including ISO 14 000 (EMS) series for an environmentally sustainable design.
- Improving macro-economic policies.
- Extensive education for practising engineers and designers to acquire skills in the expanding design process and its methods.

Systematically, priorities should be defined, problems outlined and finally, the best proposals adopted. While it is true that immediate implementation regarding these issues is not practical, the authors hope, however, that these issues can be included in future research and development agendas.

7 References

BRE Information, 18/82 (Bonshor, R. B. and Harrison, H.W). (1982) Traditional Housing: *A BRE study of Quality. UK.*

CIB (1997). CIB Coordinators' Trend Reports. *An anthology of Future Perspectives. Publication 211. CIB*, Rotterdam.

Frohnsdorff, G.J. and Martin, J.W. (1996) Towards Prediction of Building Service Life: The standards Imperative. *7DBMC*, Stockhokm, Sweden. 19-23 May 1996. Vol. II,pp. *1417-1427.*

Haagenrud, S.E. and Henriksen, J.F. (1996) Degradation of Built Environment Review of Cost assessment Model and Dose-response Functions. *7DBMC. Proceedings of the Seventh International Conference on Durability of Building Materials and Components.* Stockhokm, Sweden. 19-23 May 1996. pp. 85-96.

ISO/ TC 59. (1998) Building Construction. *Working (research) document.*

Kibert, C.J. (1998) The Limits to Sustainability. *CIB World Building Congress 1998*, 7-12 June, Gävle, Sweden. *Materials and Technologies for Sustainable Construction. Construction and the Environment*, pp. 2169-2176.

Makenya, A.R. (1996) Building Systems for Affordable Housing in a Developing Country. *CIB W89 Beijing International Conference*, 21-24 October 1996. File: D:/Papers/ 240_ 249/P241.HTM.

Makenya, A.R., Rwelamila P.D. and Chobya, L.A. (1998) The construction industry and sustainable housing for the next 21st century: The eastern Africa case. *CIB World Building Congress 1998*, 7-12 June, Gävle, Sweden. *Materials and Technologies for Sustainable Construction. Construction and the Environment*, pp. 789-794.

Mitchell, M. and Bevan A. (1992) Culture, Cash and Housing. Community and Tradition in Low-income Building. VSO/ Intermediate Technology Publications, London.

Sarja, A. (1998) Integrated life cycle design of materials and structures. *CIB World Building Congress* 1998, 7-12 June, Gävle, Sweden. *Materials and Technologies for Sustainable Construction. Construction and the Environment*, pp. 827-834.

Soronis, G. and Makenya, A.R. (1998) Towards a new integrated ISO-Standard for Sustainable Building. *CIB World Building Congress 1998*, 7-12 June, Gävle, *Sweden. Materials and Technologies for Sustainable Construction. Construction and the Environment*, pp. 467-472.

Lippiat, B. (1998) Building Environment and Economic Sustainability (BEES). *CIB World Building Congress 1998*, 7-12 June, Gävle, Sweden. *Materials and Technologies for Sustainable Construction. Construction and the Environment*, pp. 779-788.

United Nations Centre for Habitat Studies, UNCHS (Habitat). (1996) Global Report on Human Settlements. Oxford University Press, Oxford.

PART FOURTEEN

LIFE CYCLE ANALYSIS AND SUSTAINABLE, DURABLE DESIGN

DESIGN FOR DURABILITY

198 DESIGN FOR DURABILITY? — A SPECIFIER OBSERVED

S. Emmitt

Leeds Metropolitan University, Leeds, UK

Abstract

The concept of designing for durability (or taking an environmentally responsible approach to building) is well established; however, research has indicated that the uptake of such practices is slower than anticipated. The specification of building products is important, but an area poorly researched, compared with the initial design phase. In an attempt to shed some light on the product selection process, a specifier was observed as part of a larger investigation into how designers become aware of building products that are new to them - building product innovations. The observations, carried out over a three year period within an architectural office, raised a number of issues about sustainable product selection, whilst also raising a number of methodological issues relating to the observation of the specification process. Analysis of the information identified a number of different pressures to change the product from various participants in the project, occurring at different stages; from initial awareness and selection by the specifier, through the competitive tendering stage, to pressures to change on site, before the product was eventually built into the building. The paper concludes by discussing the findings with regard to sustainable practice and designing for durability - do they indicate good practice or bad habit?

Keywords: building products, detail design, diffusion of innovations, durability, information overload, risk management, specification substitution.

Durability of Building Materials and Components 8 (Volume Three). *Edited by M.A. Lacasse and D.J. Vanier*. Published in 1999 by NRC Research Press, Ottawa ON K1A 0R6, Canada. ISBN 0-660-17742-0

1 Introduction

The number of building products that are potentially available for selection by an architect is extensive. Every year new products are introduced by manufacturers in response to competition, new regulations and changes in architectural fashion. In addition to these 'new' products, there are numerous minor product improvements that are constantly introduced by manufacturers to prolong their product's life on the market. These new products and product improvements, like the established products, are all dependent upon decision makers in the building industry for their selection. A process generally referred to in the building industry as 'specification'.

Although the architect's responsibility for building product selection has declined in recent years, they are still the most influential and important 'specifier' of products in the British building industry (Barbour Index 1993). Indeed, architects have been described as 'licensed specifiers' (Pawley 1990:5), and their influence over the majority of product selection is well recognised by the building product manufacturers who bombard architect's offices with their trade literature. Research into the selection of building products by architects was carried out by Margaret Mackinder (1980), who gathered information about detailed design decisions from diaries filled in by participating architects. From this she observed that architects frequently used 'short cuts' based on their own experience in order to save time, reporting a strong preference for certain materials and components that they had used previously, drawn from their personal collections of literature; supporting the earlier observations of Goodey and Matthew (1971). Indeed, one third of those interviewed by Mackinder noted that it was office policy to avoid the use of anything new unless it was unavoidable, preferring to stick to familiar products when specifying. Although Mackinder's sample acknowledged that new materials and components needed to be monitored in case there were advantage in terms of cost or performance, there is little evidence of research into the process by which architects become aware of products that are perceived as new to them, 'building product innovations'.

The majority of published literature that has investigated the way in which architects make decisions has concentrated on the 'design process' with emphasis on the resulting 'design' (Rowe 1987). Commonly referred to as 'design methods' literature it was concerned with creative problem solving and sought to describe the design process as it should be carried out, rather than how it is carried out. More importantly, in the context of this paper, the architect's use of specific building products or the process through which the designer has passed to reach this decision is rarely discussed (Leatherbarrow 1993:143).

The larger research project from which this paper is drawn applied the diffusion of innovations model (Rogers 1995) to the building industry for the first time, with a focus on the specifier's 'innovation-decision process' and the consideration, selection and rejection of building products that were perceived as new by the specifier, i.e. building product innovations (Emmitt 1997). The case study reported below was supported by other research (conducted over a three year period), namely a diary of adoption and an extensive postal questionnaire, itself supporting the earlier work reported above, and there was no evidence to suggest that the behaviour reported here was not typical.

Clearly specifiers do adopt building product innovations, but what makes them look outside the palate of favourite products and engage in an active search for building product innovations that satisfy particular criteria? This paper focuses on the individual specifier's innovation-decision process in an attempt to shed some light on this question. The case study is concerned with the factors which cause a specifier to look beyond his palette to building product innovations and the ensuing innovation-decision process. The observation is described as a series of distinct steps, which are then compared and contrasted with the theoretical innovation-decision making model. It is concerned with a part of the design process, detail design, that has largely been ignored by the design methods authors and on which little research has been published. This is important research, both from the manufacturers viewpoint and from the viewpoint of those interested in the selection of products that contribute to an environmentally responsible approach to building, because the majority of environmentally friendly products will be new to the specifier and thus constitute an innovation to the individual.

2 Methodology

As noted above, the research reported here formed part of a much larger study into the diffusion of building product innovations. The observation of a specifier working in an architectural office provided an ideal opportunity to observe how often, and why, a specifier considered the selection of products that he had not used before, i.e. were not included in his palette of favourite products. The observation was conducted in the design office of a well established architectural practice that concentrated on industrial, commercial and retail developments, approximately 90 per cent of the work carried out by the firm was new build work, the remainder being refurbishment projects. From the associated research (Emmitt 1997) it appeared that the consideration of product new to the specifier was a rare event, therefore participant observation appeared to be the only way of observing the process.

There is a problem with this type of research because the observer has to be present when the events occur. The objective of the research was to observe a situation or event that caused a specifier to investigate 'new' products, therefore the specifier(s) would be self selecting and there was a danger that the critical event may not occur when the observer was present. What was significant, was that the opportunity for observation did not occur for a considerable amount of time because specifiers in the office continued to select products that were familiar to them, thus demonstrating that the adoption of building product innovations is a rare event. Eventually a situation arose that could be observed and recorded for the duration of the process. The specifier observed sat next to the author and had the unusual habit of talking out loud whilst he was working: although this irritated other members of the office, it made for an ideal subject since the thinking process and the decision-making process, usually hidden from an observer, was quite transparent. The observations recorded below provided an illustration of the specification process which could be compared with Rogers's (1995) innovation-decision process (reported in the larger study).

3 A specifier observed

The specifier was allowed two weeks to produce the production information for four retail units, to be built under one contract by a contractor that the architectural practice had worked with on previous occasions. All four units were being built for specific clients, it was not a speculative development: three of the units were designed with timber rafters and concrete interlocking tiles for the roof covering, whilst the fourth unit was to be detailed with a structural metal tray and a profiled steel roof to suit a client's request. The specifier's actions are detailed below as a series of steps.

Step 1: was to detail the three units with the tiled roof, a task that was carried out quickly because the specifier was familiar with this form of construction. His previous project had used a very similar roof construction; indeed the drawings produced for it were used to gain information for use on the current project, in addition to information taken from the specifier's own collection of literature. When he attempted to detail the metal roof, a form of construction which was unfamiliar to him, he was unable to draw on his previous experience because he had not worked on any similar projects, although other specifiers in the office had. Furthermore, his palette did not contain any information which would help him; he was forced to look for products, i.e. actively search for information about building product innovations to solve his particular need.

Step 2: was to ask other specifiers in the office if they had used a suitable product recently on other projects; so he first sought peer group recommendation, drawing on their previous experience. This step was taken to "save time looking in the library". The office palette of favourite products did contain a manufacturer's roofing product, which had been successfully used before, Product A. This product was new to the specifier, (although he knew of the manufacturer), i.e. a building product innovation. He spent approximately ten minutes talking to his colleague about the product, primarily to gain more information and to establish whether or not the product was suitable. He was seeking to reduce his level of uncertainty which is consistent with Rogers's model.

Step 3: satisfied with the information gathered through interpersonal contact, he then sought further information about Product A from the office library. Although trade literature about this product was contained in the office library it was not comprehensive enough to solve all of his queries, therefore, he telephoned the manufacturer to ask for additional literature. During this telephone conversation the manufacturer of Product A offered to send a trade representative to the office to assist with any queries: this was declined by the specifier. The information was received three days after the request, (during which time the specifier had been working on another project). After reading the information, he decided to specify Product A and continued with his detail design, thus at this stage the product had been adopted.

However, the following day he discovered a technical problem, specific to the shape of the roof, which could not be resolved by the literature alone, therefore he telephoned the manufacturer's technical department for further information. During the telephone conversation it became clear that Product A would have to be modified to resolve his problem, but the manufacturer did not have a 'standard solution' because they had not considered such a possibility arising. This resulted in a state of dissatisfaction on behalf of the specifier, who immediately after the telephone call went to the office library to search out an alternative. He did not use the electronic database or the printed product compendia, he selected entirely from the trade literature on the shelf (confirmed with specifier).

Step 4: from his search in the library a further three building product innovations were selected, (the library contained trade literature from ten manufacturers of similar products). The specifier telephoned the technical department of all three manufacturers to question them about their product, and to check whether it could solve his particular problem. Product B was discounted because the technical representative was seen as not knowing his product well enough (described as a "complete idiot" by the specifier). Product C was rejected because the company would only answer technical queries by sending a trade representative to the office; since the earliest appointment was in seven days time it was unacceptable and the product was rejected. Product D was adopted because the technical representative "knew his stuff" and had offered some practical advice to the specifier which helped him to complete his detailing quickly. Approval was then sought from the technical partner and was granted. The product and company were referred to by name, both on the drawings and in the written specification. This information was then sent to the quantity surveyor for production of the bills of quantities and also for a cost check of the design against the original budget.

Step 5: during the three weeks that the quantity surveyor took to complete the bills of quantities and produce the cost check, which was in excess of the original budget, the quantity surveyor telephoned the specifier to suggest an alternative (and cheaper) product to that already specified in order to save money. The alternative, Product E was unknown to the specifier, i.e. a further building product innovation had been introduced to him. This was immediately rejected because he had invested a lot of time in solving a particular problem and did not want to go through the process again with a different product and different fixing details. He made no attempt to analyse the information, despite the potential cost savings reported by the quantity surveyor, and Product D was included in the information sent out to competitive tender. This illustrated the contribution made from outside the architect's office during the specification process, with pressure to change the specified product and also the introduction of knowledge about additional product innovations, confirming stage 3a. Furthermore, the effect of time on the process appeared again which is specific to the specifier and not part of the Rogers model.

Step 6: the lowest sum submitted was accepted by the architect's office and the client. But the lowest tenderer had also submitted another, lower, contract sum for a revised specification. Enclosed with the alternative tender sum was a list of products which had been specified by the architect's office and a list of cheaper alternatives proposed by the contractor; twenty three products had been identified, ranging from the facing bricks and cavity insulation to the ironmongery for the internal doors, plus the steel roofing system, Product D. Thus a further innovation had been introduced, Product F. Individual product costs were not listed, instead a total cost saving had been identified compared with the original products specified. The client asked the specifier to analyse the alternative tender sum and then advise him which to accept.

The proposed alternative, Product F, was unknown to both the specifier and the office. Although he wanted to reject the innovation immediately, further information had to be sought so that a report could be made to the client. He telephoned the manufacturer of the product and asked a number of questions about delivery and guarantees. The answers raised further issues to be investigated and since he did not have the time to pursue them he rejected Product F on the strength of the telephone call. The architect recommended to the client that the alternative specification be rejected because the cheaper products were of insufficient quality or were not acceptable visually, (e.g. the facing brickwork). The contractor was appointed with no change to the original contract documents.

Step 7: once the contractor had started building, further attempts to change a number of products, including Product D, were made by the contractor. First, the contractor claimed that the specified product could not be delivered to site on programme (this was found to be untrue when the architect checked with the manufacturer) and second, the contractor proposed that Product F be substituted to save money. Both requests were denied by the specifier. Product D was delivered to site and built into the building, thus, after a number of attempts to change it, it was finally adopted. Information about Product D was added to the specifier's palette. This provided evidence of the theoretical stage 4a, specification substitution.

4 Interview with the specifier

When the observation period was complete the specifier was interviewed, during which questions about the process of specification and his attitude towards building product innovations were addressed. Although the specifier described himself as creative and always looking out for new products he was aware that his actual behaviour was contrary to this. He claimed that he was "forced to be conservative" because of both his own, and the office's, concerns about the possibility of building product failure. He described this as a form of risk management, a technique that relied, primarily, on his own palette of favourite products.

His palette of favourite products had been assembled over a 25 year period in the building industry from products that he said were "known to perform", (i.e. he believed that they would not fail). Some of this information dated back to 1976 (!) and was still referred to, in spite of the office quality assurance system that forbade the use of out-of date literature. Information about a building product innovation would be added to his palette if a new situation had forced its consideration and if there were no problems in specifying it or any problems reported from site during or after construction. Trade representatives were only seen or spoken to by telephone when further information was required for a specific project; so communication with building product manufacturers was always initiated by the specifier. Two reasons for looking outside his palette were recorded in the interview, namely technical substitution and a new situation:

1. Technical substitution: would arise if the product in the specifier's palette was not suitable for the given situation. This would result in a search for information about other products, which may themselves eventually enter the palette.
2. A new situation; would arise if the specifier was engaged on a different building type to that normally commissioned, resulting in the need to search for different types of building products (as noted in the example above).

Both of these situations would result in the specifier engaging in an active search for information. He also said that he tried to stick to products he had used previously because the time pressures imposed on him by both the design programme and the construction programme rarely allowed him any time to investigate alternatives. At the time of the observation the specifier was working on three other jobs, all at different stages, and all with demanding programmes.

The case study did not observe the confirmation stage because during the monitoring period the specifier did not have an opportunity to specify the product again. However, he was asked if he would use the product again to which he replied, "Yes, if I need to".

5 Discussion

At different stages in the innovation-decision process contributions were made from outside the architect's office by a number of external contributors, namely the quantity surveyor and contractor, who influenced the specification process at different times; important to recognise, since the external contributors have the potential to resist the adoption of a 'new' product and/or introduce 'new' products to the specifier. Thus the uptake of environmentally friendly products may be influenced (resisted or promoted) by other members of the temporary project team.

It was the failure of the specifier's palette of favourite products which led to his search for information about building product innovations to satisfy a particular need. So although information about products had previously been communicated to the office, via trade literature, journal advertisements and listings in the product compendia, this case study showed that manufacturers were reliant on the specifier searching it out or becoming aware of the information through a third party, an external contributor.

The case study was concerned with product innovations which were to be used on the exterior of the building and would be visible when the building was completed, which perhaps explains part of the specifier's reticence to change his original decision. However, the specifier said that he rarely had time to investigate "new products" because of the pressures of the building programme and noted that this aspect of his job, whilst important, had to be balanced against many other duties. This behaviour was consistent with earlier research that reported the tendency to act conservatively and rely on products used previously, both to save time and reduce risk.

We should not be surprised by the specifiers behaviour. Parallels can also be drawn with research in the field of medicine. The behaviour of the specifier observed above is consistent with diffusion studies in medicine. Other studies into repeat prescribing (Harris and Dajda 1996) have shown that medical drugs can be prescribed, without reference to the doctor and there are comparisons here with the use of standard details by specifiers to save time - like the patient's drugs, the products have not been re-assessed, merely applied because they worked successfully before. The danger is of course that the situation may not be the same and the both the patient and the building may not be getting the correct prescription.

So, to the question raised at the start of this paper. Does the behaviour observed indicate good practice or bad habit? The answer to such a question depends to a certain extent on one's perspective.

1. From the architectural firm's point of view, this behaviour could be seen as good practice, since it shows effective use of time and risk avoidance techniques (although the use of out of date trade literature would be seen as bad habit). As pressures on time and resources increase there is likely to be greater reliance on standard details, products and design typologies - the tendency here will be to reinforce conservative behaviour and reduce the potential for the specification of products new to the office unless absolutely necessary.
2. From an environmental point of view the use of familiar products and details does not necessarily mean that all is well. Many standard details have design faults and many products prove to be less durable than the manufacturers claimed some time after they have been used in the building. Furthermore, the use of new materials that may be more durable and/or more environmentally friendly is likely to be restricted by the specifier's behaviour reported above. For environmentally friendly products to be specified en mass there needs to be a change in behaviour, which given the observations discussed above, may be easier to state than actually bring about.
3. From the building product manufacturers perspective. Those trying to introduce new products face resistance, whilst those intent on maintaining the status quo will find some comfort in the research reported above. For the producers of products that may have less impact on our environment and longer term durability (not necessarily linked) life may be tougher than they would like to acknowledge.

From the vast amount of empirical diffusion studies it has been shown that getting a new idea or product adopted is difficult, and it takes time. Applied to the specifier in an architect's office the diffusion model has shown that building is no different in this regard - change will be slow. The specifier was designing not just for the durability of the building but for the durability of the architectural firm, by limiting his firm's exposure to risk.

6 Conclusion

Rogers (1995) questioned whether it was the need for an innovation, or the awareness of an innovation, which comes first in the innovation-decision process. The research has shown that specifiers actively search out building product innovations only when the need arises, and not before. The implication here is that the adoption of 'new' environmentally responsible products may face considerable resistance; not just from the specifier, but also from the other contributors to the specification process.

It is this author's view that the specification process must be understood fully. At different stages in a building's life cycle decisions regarding the selection of building products are made, both at design stage and during maintenance, repair and improvement programmes. At all of these stages the individual specifier (whether an architect, building surveyor or jobbing builder, will go through the innovation decision stage when selecting products. Obviously, the long term durability of the building will be reliant on, and affected by, the building products actually used. By gaining a fuller understanding of the individuals innovation-decision process, both professional design offices and the building product manufacturers, will be better equipped to consider the use of materials that can contribute to an environmentally responsible approach to building. Then, and only then can the process be managed and environmental impact of building products be addressed as part of the whole.

7 References

Barbour Index (1993) *The Changing Face of Specification in the UK Construction Industry*, Barbour Index plc, Windsor, Berks.

Emmitt, S (1997) 'The Diffusion of Innovations in the Building Industry', PhD thesis, University of Manchester, Manchester.

Goodey J. and Matthew K. (1971) 'Architects and Information' Research Paper 1, Institute of Advanced Architectural Studies, University of York, York.

Harris, C. M. and Dajda, R. (1996) 'The Scale of Repeat Prescribing', *British Journal of General Practice*, November, **46**, pp. 649-653.

Leatherbarrow, D. (1993) *The Roots of Architectural Invention*, Cambridge University Press, Cambridge.

Mackinder, M. (1980) 'The Selection and Specification of Building Materials and Components', Research Paper 17, Institute of Advanced Architectural Studies, University of York, York.

Pawley, M. (1990) *Theory and Design in the Second Machine Age*, Basil Blackwell Ltd, Oxford.

Rogers, E. M. (1995) *Diffusion of Innovations* (Fourth edition), The Free Press, New York.

Rowe, P. G. (1987) *Design Thinking*, The MIT Press, Cambridge, Massachusetts.

199 BUILDING DURABILITY — KNOW WHAT YOU KNOW OR LET'S USE THE KNOWLEDGE WE ALREADY HAVE, BEFORE WE IMPROVE UPON IT

W.H. Gumpertz and D.A. Rutila

Simpson Gumpertz & Heger Inc., Arlington, MA, USA

Abstract

We encourage the use of our professional experience to get the most of old and new materials and construction methods to obtain durability in buildings, by better and more consistent use of knowledge we already have. Recent experience shows that major buildings fail in their function after as little as 30 years for disparate reasons. We examine some of these reasons by looking at practice of design, contracting and construction as follows: things designers know or don't know; when contractors build, do we know enough?; the manufacturer's contribution B or lack thereof; and, how we organize labor and material.

Keywords: construction, design, durability, materials, service life

1 Introduction

Innovation is great. Without innovation, the construction industry would still be dealing with caves and mud huts, and palm fronds. But innovation also carries risks in use of new and existing materials and methods.

This paper reports on the use of our professional experience to get the most of materials and construction methods to obtain durability, by better and more consistent use of knowledge we already have. Based on our extensive investigatory experience, major advances in durability can be achieved by learning why some buildings fail by malfunction of a concealed, but crucial, component or use of inappropriate technology.

Ideally, a well designed and constructed building should live B with proper maintenance B for its whole expected (economic) life B without repairs.

Durability of Building Materials and Components 8 (Volume Three). *Edited by M.A. Lacasse and D.J. Vanier*. Published in 1999 by NRC Research Press, Ottawa ON K1A 0R6, Canada. ISBN 0-660-17742-0

Durability requires, in addition to appropriate selection and use of materials, maximum degree of flexibility in the physical plant to anticipate new uses. Recent experience shows that major buildings fail in their function after as little as 30 years for disparate reasons. We examine some of these reasons by looking at our practice of design, and experience with contracting and construction as follows:

2 Things designers know or don't know

We expect designers to be knowledgeable about the selection and use of construction materials, components and equipment through their education and experience. Learning must be life long because construction materials, components and equipment are constantly changing through innovation, success, and failure.

2.1 Choose materials for proportionate durability. What materials matter in durability? What do we know about them? What don't we know?

The greater the cost of failure of a building material, the greater its need for durability, which is defined as life expectancy in the selected environment. The cost of failure is all expenses, including consequential damage as well as replacement cost.

Roofing - The cost of a roofing replacement should be modest in a properly designed building (i.e., where roofing replacement is anticipated in the original design), but the disruption and damage caused by a sudden and ill-timed roofing failure can exceed the value of the roofing many times. Consider the sudden, cold weather shattering of an unreinforced thermoplastic roofing membrane. Years ago, we designed the roofing for a large, golf ball-like structure (50 m diameter) with its roof membrane covered by reflective, faceted panels that are not waterproofed. We selected the most durable membrane that we could identify because we wanted to avoid removing the panels, and we have not, to the present date.

Structures - Durability of structural systems is critical because everything on or within the building is affected by failure. Steel, reinforced concrete, masonry or wood structures of most buildings are designed to be within a weatherproof envelope. Experience shows that the mass of these structures is generally adequate to withstand occasional leakage when roofs or wall systems fail. Problems occur when these structural systems are exposed to weather by design without special consideration, or when they are exposed to weather through inadequate protection. Examples include: thin metal studs used in back-up wall framing of curtain walls where unnoticed leakage destroys this structural system; reinforced concrete balconies that project beyond the cladding without reinforcing cover or concrete quality necessary for durability (a coastal environments adds insult to injury).

Components and Equipment - consider the ventilating equipment installed on the roof, with a thin sheet metal condensate pan that fails to drain water; we recently found it less expensive to replace the units than replace just the pan, since the entire unit had to be disassembled. These same pans were a source of fungal contamination that was distributed through ducts; the ducts needed cleaning but several components (variable air volume boxes) had to be replaced because they were not designed to be cleaned adequately.

2.2 The mystery of new materials and their applications. What are they? What do we know about them? What should we know about them? Why?

Construction has left us with many examples of experiments in new materials and designs. We continually come across abandoned technologies, such as:

- Two-ply built-up roofing - Hailed by the slogan, "one plus one equals four" the industry soon learned that their product was as faulty as their arithmetic.
- (Too) Thin stone veneers - Quarry, fabrication, and finishing technologies allowed designers the option of large, thin (often less than 3 cm) granite and marble veneers. Coupled with truss and precast concrete mounts that allowed greater shop fabrication, thus removing stone setters from building sites, thin veneers were constructed on many buildings. Some stones proved dimensionally unstable, or stones failed at anchors given the local stress. Today, we continue to pick up the pieces and remediate these systems.

We prefer to select materials where we know the performance based on years of experience, but it leaves little room for innovation. We offer some guidance:

- Determine what is or is not known B Most new materials are "improvements" or variations on an existing technology. We try to identify what is the same and what is different between new and old technologies. Often, testing the product can answer some of the questions, but it can be an imperfect quest. We were asked to predict the performance of gold leaf on granite. We found that gold leaf has not historically been applied to granite, so its durability had not been tested, in the laboratory or in the field. We tested samples using standard masonry durability tests, absorption after 24 hour boil, freeze thaw, etc. We were able to conclude that if you boil the building and then freeze it, the gold leaf would be durable. We did not know the real world affects rain acidity, birds, etc.
- Check the performance history - We commonly hear about the latest European technology, which always has an impressive European track record. We have gone to Europe over the years to evaluate claims and from time to time find truth in some. Similarly, we are given project references in this country. When we check on them, it is amazing how often we find performance problems; clearly most people do not check references by contacting maintenance personnel.
- Compare the innovation with the alternative - If an innovative material is being used to save money, compare the consequences of failure to the savings. If the material must create an image and there is no alternative, try a different image.

2.3 Compatibility, or how to combine things to make trouble. What combines with what to make trouble? What do we need to know about compatibility?

Compatibility means several things to us. The simplest is chemical: place many polymeric materials such as common building sealants in contact with an asphalt product and the asphalt may bleed "oils" into the polymeric material causing failure. Or, place an asphalt product in contact with a coal-tar product and, if both are new, you may see a sticky oil at the interface as the chemicals combine. This unintended chemistry causes many waterproofing materials to fail prematurely.

Compatibility also addresses two or more materials that might be durable, but which are not be combined in a durable assembly. Consider damage to single-ply roofs on flat, one story schools; expansion of gypsum accelerators in stone setting mortar; or corrosion from copper flashing over aluminum window frames.

2.4 Murphy's Law - or how poorly selected materials are hardest to get to

Defects that are easy and cheap to fix generally get fixed. More expensive defects go unrepaired. We find the following history at many buried plaza decks: design development B it cannot leak; design - we cannot have a proprietary specification; value engineering B the specified system is too expensive; construction B the subcontractor can prepare details in the field; water test - there isn't time; dispute B it's too expensive to fix or argue about so the contractor injects the cracks.

3 When contractors build, do we know enough?

3.1 If everything else fails, read the specifications

Quality matters. Other things being equal, strict compliance with the design (i.e., drawings and specifications) has a direct effect on the quality, and hence durability, of a building. We have already discussed the importance of correct design; now how does the contractor look, from his viewpoint, on the contract documents?

- They should be clear and comprehensive.
- They should be terse and as short as possible, so that field personnel can read them easily and find pertinent provisions easily.
- They should be free of repetition, in drawings and specifications.
- They should be free of any item that the designer thinks "would be nice to have" but which he does not plan to enforce.
- They should indicate the degree of freedom for contractor substitutions.
- They should be up-to-date-codes, published standards, and materials.
- A place for everything, and everything in its place: work for each trade should be identified and put into one location.

There are other requirements, which indirectly affect durability. Once the contract documents are of high quality, it is easier for the contractor to enforce high quality workmanship. As a matter of experience (and based on Murphy ' s law), quality affects the invisible components to a greater extent; hidden components are frequently the most important ones, and the most costly and difficult to repair.

What are the most critical, or frequently invisible, weaknesses that affect a building ' s overall durability? Here are some examples from our experience:

- Wall flashing reversed, to channel rain water into the building.
- Exterior wall panels made with material dissolved by water.
- Through-wall flashing that disappears after some years.
- Artificial roof slates that self-destruct after two years.
- Wood foundation walls that disintegrate below ground level.

- Impregnated plywood sheathing that turns to dust in summer heat.
- Roof insulation that age-shrinks and tears built-up roofing.
- Gym flooring exploding because of the absence of perimeter expansion space.
- Pile foundations that failed due to sulfate attack.

All these defects have one thing in common: they compromise durability, interfere seriously with the function of the building, and are costly to repair, primarily because of the difficulty of gaining access to the component requiring service.

3.2 The eye of the farmer makes the corn grow

This old saw from the Midwest farm belt touches on the weakest factor of any construction work. Absence of construction supervision causes permanent damage for temporary gain. Many general contractors (as well as construction managers) "contract out" all work to subcontractors, and become, in effect, brokers and paper shufflers. They assume that all their subcontractors not only know their business, but will follow their part of the contract documents. The general contractor "coordinates" the work primarily by scheduling and processing payment requisitions. Absence of competent supervision filters down to the lowest level. In many of our failure investigations, we start interviewing the contractor's management to get the history of the projects. More often than not, we are referred to the superintendent, who is not sufficiently familiar with the job history to help. We then get referred to the foreman, who wants us to talk with the mechanics who did the work. When (and if) we speak to the workers, they refer to the laborers who mixed the mortar or set other components.

3.3 Value engineering - minimal savings at maximum damage

The idea of value engineering is sound: a contractor may, using his knowledge and expertise, find a way to save money by changing materials and methods without reducing quality. In reality, value engineering proposals are rarely studied for the contingent effects, and are frequently judged by the owner on money savings, without regard to the original design. Examples of defective value engineering are:

- The contractor suggested replacement of metal through-wall flashing with a plastic product that hardens with time. The owner derived a $7,000 saving. When the plastic flashing hardened and cracked, the resultant water leaks went out of control. The developer was forced to rebuild at a cost of $25,000,000.
- An owner was persuaded to cover a leaking roofing system with a single-ply material, instead of removing the wet original system first. As a result, the steel deck corroded to the extent that much must be replaced.
- In an office building, money was saved by using a once-through water cooling system instead of a heat exchanger to separate the deep-well water from the interior system. After a few years, all of the unit heaters, and much of the distribution system, disintegrated because of the high oxygen content of the well water.

Our experience with value engineering decisions has taught us:

- Change proposals rarely receive the attention that the original design received.
- The savings to the owner are not usually commensurate with the risks.
- If a designer's plans require improvement of components for purposes of saving money without loss of quality, the designer should make the needed changes to begin with. If he/she/it is incapable to do so, the owner needs a better designer.
- Value engineering helps our business, but it is bad for our clients.

3.4 Every craftsman can make the designer and contractor look good - or bad

Close monitoring of the construction work is needed to protect the owners from poor work, the designer from loss of reputation, and the contractor from legal action. We have learned that most mechanics have it in their power to make their employer (and others) look good or bad. We have seen, in a matter of minutes, a sloppy worker turn into a master craftsman when motivated B or competently supervised. Since most of the defects caused by poor construction methods are built into the hidden parts of the building, supervision and motivation are necessary to ensure durability.

3.5 Quis custodiet ipsos custodes? (Who will watch the watchman?)

Some projects require the contractor to provide and pay for all testing, or even for a quality control program. The above Latin proverb is appropriate warning that such procedures constitute a conflict of interest for the supervisors. Quality supervision avoids incomplete or even lax monitoring of the work, and protects the owner; it should be paid for by the owner.

3.6 Guarantees and manufacturer's inspections

Most owners consider manufacturer's guarantees paramount in deciding on major material components for their buildings. This has an adverse effect on the quality and durability of the building. Guarantees mislead, because:

- Guarantees give a false sense of security. A functioning building is much better.
- A guarantee often limits the owner's choices, excludes part of the direct and consequential damage from any failure, and subjects him to unfavorable conditions. Many roofing guarantees require the manufacturer to keep a roof "functioning," even if it has failed to keep the building dry. The owner will get nothing for insulation damage, loss of content, business disruption, and uncertainty about the future of the building. Guarantees are a "license to litigate" or a "parachute warranty" (if your parachute fails, you get a new one if you bring the old one back).
- Guarantees may relieve the contractor and subcontractors from any sense of responsibility for a workmanlike performance, or may tempt him to violate the contract documents, dumping all the blame on the guarantee and its maker.

In many cases our insistence on compliance with the design has been countered by the argument that the manufacturer has judged the work to be good enough to issue a guarantee. In this way, a guarantee has a bias against quality in construction. We insist that the owner wants a good building, not a piece of paper.

4 The manufacturer's contributions - or lack thereof

4.1 We build with materials

We design and build with many materials. The construction industry is virtually the only industry where the completed product is unique and never repeated in its original form. This limits the opportunity for using experience in testing the product's performance. The whole industry B owners, designers, contractors, and manufacturers B has to reinvent the wheel for each single project.

Each new product puts the construction team at risk, as does each new combination of established materials. Yet we must use innovation, i.e., new materials for buildings, or we would still reside in grass huts or caves. How to do that?

4.2 Old materials, new materials, and how do we judge?

Construction materials have changed a great deal, and quickly, even in the last fifty years. Wood, steel, bricks, concrete were in use for a long time, but their shapes, content, and utilization have changed considerably. New materials and/or applications have arisen, whose integration in the building process have, at times, been problematical. Among some of the new materials are plastics, composites, and old materials used in new ways, such as aluminum, and glass. Some valuable materials, such as asbestos, have disappeared because of political pressure.

How have these new materials, and their combinations, performed? Not always well enough. The fragmented industry makes feedback difficult, and the uncontrolled use of materials and systems has clouded the opportunity to learn from past experience. That applies to designers, contractors, and manufacturers.

4.3 How do new products come on the market?

The materials used in the construction of buildings come from a variety of sources. In addition to the conventional materials, new products, and new uses of old ones, originate from the following sources:

- Import of products and ideas from Europe (single-ply roofing, foam concrete).
- Changes in a nonconstruction industry producing byproducts (modified roofing membranes, microsilica concrete, engineered wood).
- Loss of byproducts used in construction because of industry changes (reduction of coal-tar pitch because of changes in the steel industry).
- Overcapacity of an existing industry because of technical change (artificial rubber products by the tire industry; recycled products).
- Development of new technology with old materials (prestressed concrete, new sealants, curtain walls and windows).
- Results of high technology development in other fields (equipment controls, HVAC improvements, communications).
- Development within the construction industry (improved flashing technology, wind testing of windows, wind dynamics).

4.4 How well have the new products performed, and why?

The success of newly introduced materials and systems has been mixed. Much of the material failures have to do with the absence of a unified industry with technical and financial resources to create and finance adequate research. Government contributions have been modest and, at times, too politically oriented; one example is the re-use of existing research facilities left over from nuclear research that are no longer needed.

Industry has gone in the wrong direction, by bringing products to market without adequate research and testing. Some industries entering the construction market have had an inadequate understanding of the specialized conditions in the construction industry. In cases where the marketing tail has wagged the technical and research dog, researchers were over-ruled with disastrous results. Too often manufacturers have made owners, designers, and contractors their unknowing and unpaid research departments by releasing products before research proved efficacy of the product.

National code organizations have, on occasion, been so influenced by industry representatives that standards included the product of the least capable manufacturer, or where standards lacked test methods that should have been designed to discover the product's suitability. We do not discount the great majority of useful and effective materials, but we have seen too many failures that have caused poor durability.

5 How we organize labor and material

5.1 How Slim Barnett did it - leadership example; or how else?

The "old fashioned" superintendent (Slim Barnett) was dissatisfied if he did not jump into concrete as it was being placed to solve some problem. Others of this breed feel the same B they want a bit of dirt on their hands as a badge of honor. These leaders showed the workers their acceptance criteria by demonstration. They know the capabilities of workers and the use of materials from experience watching and doing, not from books. They schedule by the seat of their pants during their frequent walking tours.

We still see foremen who would have, in the past, become Slim Barnett's replacement. These foreman know their trade and their industry well enough to move into the superintendent's job with additional experience and training. They remain hands-on leaders of their trade, often becoming hands-on owners of a subcontracting company.

5.2 How some modern construction managers do it (by computer) B or how quality gets swept under the rug

Today's superintendent is subservient to the construction manager. The superintendency is a subclass in the contractor's organization populated by the staff that trains for and takes the licensing exam, often provides for job-site safety, and "handles the field." The job is run by construction managers trained in estimating, scheduling, and financial matters. The superintendents, active in the field, are second to managers who are active in the trailer.

Some construction managers have no personal knowledge of how the building is assembled at the detail level. They know the basics because they schedule subcontractors, stamp shop drawings and follow the money from bid through payment. But they are not sure how flashing is assembled or how long a detail takes to install. We know, because we watch workers, but they do not. If they want an answer, they look it up or, more commonly, call their subcontractor.

If the people in charge do not know quality, or poor quality, when they see it, they cannot provide leadership to the workers by the well placed comment. Instead, the workers learn that the bosses do not know. Quality suffers.

5.3 Where is your plan table? Without one, you won't use the drawings

If the plan table is in the trailer, it's better than nothing, but not much. One trade that seems to bring their plan tables to the job with them are the ironwork erection crews. Why? Because they cannot do their work without constant reference to the erection drawings. Other trades cannot do their work properly without reference to the shop and erection drawings, but many try. We find our search to be a useful gauge of a contractor's real thinking - where are the plan tables?

You can ask the same question about any erection detail on the job. If it is in the project manager's trailer to protect their liability, they will need that protection since anything that gets built is based more on luck than controlled process. The detail needs to be at the work, in the hands of the skilled workers. The occasional reference by the foreman is the standard of many jobs, but is totally inadequate. Every group of skilled workers should be working from a plan table.

5.4 Have you handled that RFI today?

The modern construction manager sits with a staff in a trailer, reviewing RFIs (request for information), which can be the lazy subcontractor's substitution for a shop/erection drawing, or the competent subcontractor's protection against an inadequate design. In the proper place, if a contractor and designer both do an adequate job, the RFI is a plea for information by the field crew. Contractors should ask today when they don't know, and designers should answer promptly.

5.5 Is it a punch list or post mortem?

We often perform "post mortems" on buildings after a failure. Sometimes these investigations are soon after completion and sometimes years later. In both events, we find punch list files that predict the future by their focus on the problem that later became a major issue. What is most informative is how late in the project major problems were "discovered" and added to a punch list.

In the US, the standard construction contracts require the contractor to prepare a "punch list" of incomplete items at the time the contractor believes the project is substantially complete. The designer must review this list and add to it, and to assign a monetary value if money is to be held. What we find is altogether different.

The contractor rarely inspects the project thoroughly. Instead, as the designer realizes that the creation he conceived is about to be left incomplete, he prepares a punch list because he knows nobody else will do it. He soon finds the task daunting because each room needs to be examined, each window, each piece of equipment, etc. The hidden faults rarely get on the punch list.

We have no solution, only the benefit of our experience. We start early, often encouraging the owner and contractor to consider accepting partial substantial completion to create mutual benefit. All contractors must fully participate in the review at the same level of authority (gets the boss' attention), fixing little things as we go so they don't go on the list. When the contractor and subcontractor have made no effort on their own to perform the inspection, we use the list generated as a preliminary device, and continue the process after some progress is made.

6 Conclusions - how to build durability into your building

6.1 Summary

We have discussed the various influences that affect the creation of a building and how these elements bear on its durability. Durability is influenced by every component of the building's development. It is also affected by the judicious use of durable materials that are hard to reach or maintain during the life of the building (Gumpertz and Schwartz 1996). We have discussed the need of designing and constructing a building with meticulous attention to

- ! selecting materials and systems that are compatible with each other, that have at least a reasonable record of performance, that are durable within the designed lifetime, and that can be maintained and serviced effectively;
- ! building as specified, to obtain the maximum utility from the required materials and combinations, and with quality workmanship to use present craftsmanship;
- ! utilizing materials that have been researched and tested sufficiently to assure that they are fit for their intended use;
- ! eliminating trendy and untried methods and materials, especially when they are difficult to reach after construction, costly to replace, or endanger costly and critical building contents;
- ! the complexity of buildings with thousands of disparate materials and combinations, assembled by agencies that can have conflicting schedules and interests.

6.2 Conclusions

We have discussed the various components of quality that lead to long-term satisfaction in a building with reasonable durability. The choices and methods that we advocate are fully attainable with present-day technology and construction experience. While we strongly favor progress and innovation, we emphasize that constructability, good work, and maintainability leads to durability.

There are vast reserves in our present building technology, and significant improvement in building durability can be achieved by the informed use of all aspects of such technology. At the moment, we are far from building as well as we know.

7 References

Gumpertz, W.H., and Schwartz, T.A., "The well designed horse carriage, or how to design a building with materials selected for an effective service life," 7th International Conference on the Durability of Building Materials and Components, Stockholm, Sweden, 19-23 May 1996.

200 A SYSTEMATIC VIVENDI FOR DESIGN FOR DURABILITY

A. Lucchini[1] and D.P. Wyatt[2]

[1]University of Milan, Italy, [2]University of Brighton, UK

Abstract

In order to design for life a revised design and life care management procedural and decision framework needs to be developed upon building serviceability and the service life, not only to design for life but also to manage the designed service life through its life care plan. This would change the very nature and future of asset management. If such a practice was accepted, it would also place a new responsibility on those in charge of drawing up, or setting legal standards or regulatory controls, as well as those manufacturing building materials or components, or funding, insuring, procuring or maintaining buildings and above all the client and their design team. There would be then, the possibility of buildings and their constituent parts being designed and managed on their respective service lives and taken in and out of service, or dis-assembled or reused according to their serviceability and economic merits. Such practices would contribute to an extended building product life quality and life crafted and managed designs that could be under written as an insured life. In consequence, both design and service life methodologies need to be shaped to meet this new common but defined design service life practice. A change that will also include the service life and the life cycle assessment of the supply chains and building they will be located in. Adopting such an approach would also secure that whole life costed practice that would sit comfortably within the construct of the sustainable city. The new vivendi is intended to contribute to sustainable development and asset management as well.

Keywords: Design life, durability, life care, performance audit, service life planning

Durability of Building Materials and Components 8 (Volume Three). *Edited by M.A. Lacasse and D.J. Vanier*. Published in 1999 by NRC Research Press, Ottawa ON K1A 0R6, Canada. ISBN 0-660-17742-0

1 Introduction

Inevitably once designed, buildings become altered and often under go successive fit outs before finally being replaced to meet a changing society or organisational needs. During such buildings life times their respective occupying organisations end users may have cause to grumble over poor quality, or fitness or serviceability quality short comings but, at the same time, put up with such discomforts or dissatisfactions and live with them or simply up root and move on. Yet asset management has a critical role in all this, to both secure and maintain a cost effective operational environment. But until recently, asset management has largely been ineffective in either procuring service life based constructions or in identifying and recording their whole life costs of ownership let alone press for product improvement (with obvious poor results in terms of sustainability).

Why? Is it because each new design tends to be undertaken largely as if it were a prototype? It might also be observed that a design team in any event may never know themselves, how their designs have been modified or behaved over time, nor even know the associated life cost of ownership's or indeed if their design had ever failed. There is also the reminder, that in some instances, an earlier desire to either limit construction costs or optimise upon an investment return may have even resulted in some buildings or their sub-systems becoming too expensive to maintain.

The net result is that building service life problems and failure costs continue on a wide scale and the experiences of those involved in, or responsible for maintenance or asset management, may never be properly captured, or used to improve future building reliability.

In a portfolio sense there is that spectre of an unwelcome building asset or a frustration arising from an under funded re-investment into its life care. As a result, the asset management field is faced with managing as best as it can those outcomes of a wide range of client and developers respective value systems. Unhappily, though, tensioned between what was perceived as either acceptable or proffered as affordable and in the longer run, unlikely to be sustainable without a significant change in asset life and investment management practices.

New and existing buildings may in the near future be also constrained by an upper energy or CO_2 delimiter, or carbon tax or on the basis 'the polluter must pay principle' in disposing of their waste streams. Such costs could threaten essential future maintenance or building stock replacement works.

In fact, too little focus on either a building's serviceability, or the management of its service life (i.e. the service lives of its parts and elements) is given, nor is there much evidence of a serious life care replacement practice that optimises on the durability properties of the supply chains specified or used.

In short, in spite of the quality initiatives of the 80's and 90's (unlike many of the processed engineered products) building as a 'life time product' appears not to enjoy an assured quality improvement culture. Despite changes in procurement practices, the need to secure and maintain a sustainable building life remains.

2 A life modus vivendi

Nevertheless, all is not gloom, for one can recognise the growing research contribution for example, emerging from computer based product modelling protocols and building design expert systems (Scherer 1995). On such a basis, it proposed that a revised design framework should evolve based upon such developments and in turn, follow on to embrace the tenets of the ISO standards 14000, 9000, and 15686 (the latter now in course of preparation).

These ISO standards should in turn be under pinned by the auditing sense of ISO 10011, as well as relevant national regulatory standards to form part of a client's business management system based upon their 'best practice' ethos. One is really seeking to secure a designed life culture in the client business model that in effect secures that possibility of building life time quality. (Wyatt 1998a).

It is also important, to both understand and respond to the construct of a service life (Nireki 1996). Nevertheless, service lives also have to be interpreted by all those who subsequently design, specify, and have to maintain a building. In consequence, life designing should be centred around and begin with a business plan agenda that can support a building or portfolio, in such a way, that it would neither weaken the building or asset management decisions, nor reduce their life quality.

Asset management then might be appraised upon the basis of a life time status, within managing a material's durability within those respective environmental delimiters set (Noren et al. 1998) and the space and serviceability quality found. On that basis, until a better approach is found, it is proposed that the traditional design process model is re-structured or redefined to inorporate new stages. This means moving the design process on to be a life based characterisation where the design life system boundaries would be identified in a common decision making framework. In turn, this would form the basis for developing from a pre briefing stage the building performance and life scoping together with the necessary funding and management of the life costs of building ownership within some defined forecasted range.

3 Pre-briefing for service life

To improve the building's life focus, the pre-briefing stage should be formally brought to the design brief and embrace the areas shown in Figure 1.

Accepting a pre-briefing stage should promote a more measured response from within the client's own organisation experiences. It would also take pressure away from the client's project team from taking over too early in the design process and forcing changes that might not always be helpful in that design's shaping. It might also identify within the client business environment possible future threats or problems.

This pre-brief activity should essentially concentrate upon outcomes aiming to quantify the likely design life and post occupational needs and, at the same time, to improve the formal briefing quality. In effect, this move should reduce a project's time scale, encourage more realistic treatment of the life time funding provision(s) and move the procurement culture away from the first cost and claimed valued engineering to life engineering within a defined whole life cost.

In addition, during this pre-briefing, the portfolio dismission staging (including all its waste streams as well as possible restrictions in redevelopment in any future 'sustainable cities' planning authority's Agenda 21 initiatives) should also be addressed. Especially, for those areas where this may prove punitive, if sustainable tenets are enforced at some vulnerable time in the future of the trading organisation.

The portfolio, organisational and client end user needs would be better served, if they were reflected in a formal life quality framework that fitted within the client's business excellence plan and practice (Wyatt 1998b).

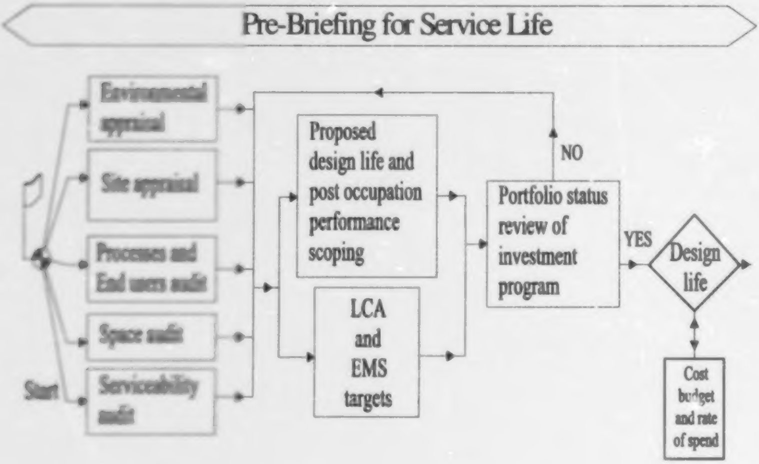

Pre-Briefing for Service Life
Environmental appraisal
Site appraisal
Processes and End users audit
Space audit
Serviceability audit
Start
Proposed design life and post occupation performance scoping
LCA and EMS targets
NO
Portfolio status review of investment program
YES
Design life
Cost budget and rate of spend

Fig. 1: Internal organisation's pre-briefing activity

Concluding, it is suggested that the pre-briefing stage should reflect the serviceability quality of the client's portfolio, including any poor life quality buildings, and have a review in the end. Outcome of the pre-briefing are the building's design life and the global budget and rate to spend.

4 Briefing for service life

Generally, it is believed that an appropriate life based philosophy should exist with definable key attributes of a life design based upon performance and service life scoped in such a way that ensures design teams can respond to the brief set. Attention should also be given to:

- the design life data and methodologies used
- the service life data available, its quality and reliability
- servicing and replacement matters

- equipment appraisal including access and mean time to failure or replacement
- life care approaches and provision to be made
- the whole life costing methodology developed and the life care funding
- service life planning (including a life time functional-serviceability analysis)
- the level and service life profiling within its life cycle assessment of those materials, components and the final building configurations planned or specified.

In scoping and developing the 'building life' target set, many practical decisions have to be made at the initial design, subsequent detailed design(s), the construction and for both the post operational and maintenance management life times. Indeed, there is a need to bring these stages that shape a 'life design' into common whole life appraisal framework, which has in part been illustrated in figure 2 below and in the other figures 1-3 and 4 and Table 1 included in this paper.

The briefing for service life is necessary to get such a framework under way also having in mind the likely management scenarios of a building's life and end of life stages including its waste disposal and possible site reinstatement requirements (Wyatt and Soronis 1998). In effect, those parties that set the life time agenda should identify the audit extent and stages and the level of transparency called for, including validating and verifying defined subsequent actions planned, or taken.

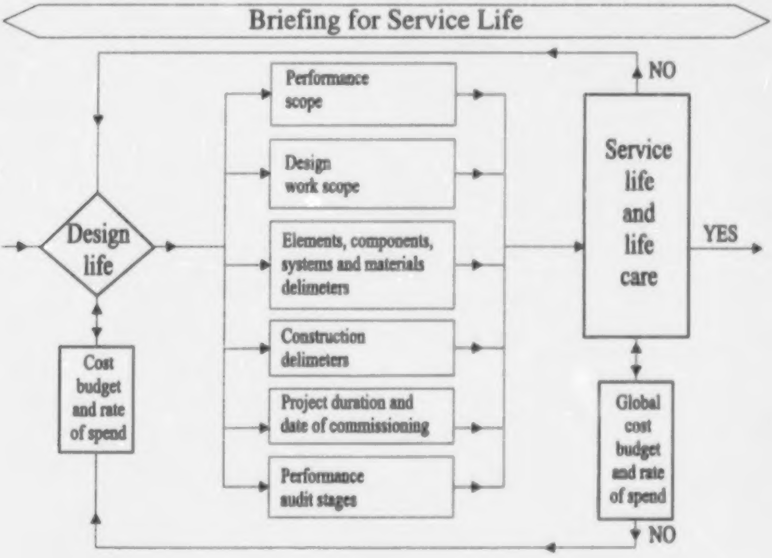

Briefing for Service Life
Design life
Cost budget and rate of spend
Performance scope
Design work scope
Elements, components, systems and materials delimeters
Construction delimeters
Project duration and date of commissioning
Performance audit stages
Service life and life care
NO
YES
Global cost budget and rate of spend
NO

Fig. 2: Service life and serviceability briefing framework

It is also important to understand that some parts of a building may fail or age before others yet such experiences may not have been recorded or have been outsourced in changing facility and asset management practices. Nevertheless there are some organisations (like hospital and housing trusts) that have detailed guidance on maintenance experiences and operational service intervals which might provide service life data. At the time of preparing this paper, such information, is not widely available.

It is noted however, that some services engineering manufactures have detailed performance and reliability data that might be hunted out. Alas generally until published tables of service lives of components etc. begin to appear say from manufacturers or test houses or insurers, in this fast developing field one must move upon the best evidence provided. Outcome of the briefing stage should be the building service life and life care specification together with the global cost budget and rate of spend consistent with the design life as well as the cost budget and rate of spend resulted from the pre-briefing stage.

5 The life design agenda

Apart from the emphasis of promoting and moving portfolio and asset management to an appropriate reflection in service life design, the product component and material service life development is also important. For it is here one would stress a systematic approach needs to be managed in order to secure a design vivendi that can respond to a range of service life methodologies or secure an appropriate life design agenda response. In preparing this life design agenda, it should also be made clear, that it is not always possible to find ideal solutions.

In fact, in establishing the building life as well as its constituent parts within changing services engineering technology and reliability development, life time operating costs value judgements are inevitable.

So it is suggested that a whole life agenda needs to be set down perhaps based upon something of the sense of Table 1 below. Here, one should read this table for the decision stages shown, moving systematically from left to right and top to bottom. In doing so, taking the sequence of design, construct, operate activities into the full design development and subsequent operational and asset management life care stages.

Finally, the design agenda must also draw attention to the need to consider the life care and dismission of the building proposal and its systems, materials and components set within a reliability or *durability* of key service lives.

6 Design

Whilst the building design phase is well understood, it is still believed that designing for life requires some additional changes if appropriate designed life buildings are to become a normal practice. Here, for example, recognising the importance of the asset management practitioner or product manufacturer's contribution in service life development or manufacturer as a provider of service life data.

Table 1: A systematic vivendi for design for durability or whole life model

Project Development	Design Development	Life Care Development
Procurement Management	Building Life Agenda	Life scoped Brief
Supply Chain Management	Life cycle assessment and Procurement cradle to grave modus vivendi	Product Management Life Care Audit
Concept	Concept Design	Detailed Design
Design Life and Reliability Engineering	Designed Life Value Chain	Service Planning for the Building's life environmental internal and external fitness for purpose
Resource Evaluation>LCA	Whole life model costing	Life care management
Serviceability	Conformance Audit	Operational Phase
Design	Product quality plan	
	Performance Life Audit	

In turn, this leaves the design team to focus upon their tasks including developing a defined life detailed building and optimising upon those service life and durability characteristics of the supply chains used or they plan to use. Indeed, Figure 3 intimates the scope of this stage and some of the decision sub routines that are believed to be necessary to be included in what is briefly set down here.

The service life figure has to be established on the most reliable data estimates available, so the attraction which the factorial approach has in service life planning (ISO 15686 Part 1 1998), especially for the non based engineering disciplines, is understandable. Nevertheless value judgements are inevitable here and how far one might take then. Yes but a start can be made, though one must not loose sight of durability research nor the engineering and statistical contribution!

Ideally, the value of each building element would match the building life or service life profiles, or cycle periods of that building life matrix. Here the component, or services assembly break down would have the defined serviceability and replacement life cycle(s) called for and a broad life cost agreed. The mean time to failure for services and the various building engineered systems as well, would be determined using an appropriate service life prediction methodology. One would, in the absence of a single service life design, accept the need for a mix of lives in any given building or system but focused upon their respective life cycle assessments (Cole 1996).

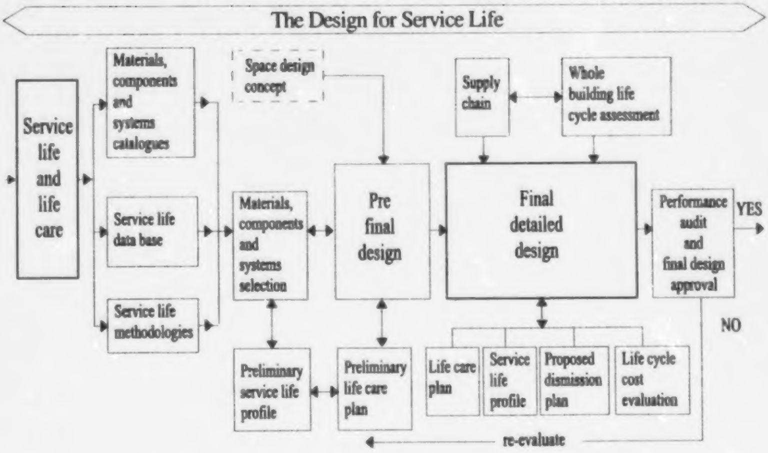

The Design for Service Life
Service life and life care
Materials, components and systems catalogues
Service life data base
Service life methodologies
Space design concept
Materials, components and systems selection
Pre final design
Supply chain
Whole building life cycle assessment
Final detailed design
Performance audit and final design approval
YES
NO
Preliminary service life profile
Preliminary life care plan
Life care plan
Service life profile
Proposed dismission plan
Life cycle cost evaluation
re-evaluate

Fig. 3: Developing the service life design

The design team should use their crystal ball and anticipate how their building may respond over the planned design agenda life time, including ageing with appropriate dignity, and how their building might be upgraded or retired to continue on elsewhere. Here durability should be seen like a life palette of 'service life paints' where the designer becomes a life artist with that ability to paint life and design blend, using old or used materials and components especially where shorter service life is required and to, in turn, blend new materials to meet any given service life profile. In consequence, the modus vivendi for the design life, should establish, reflect and bring together a broad based hierarchy of common groupings of life durations associated with the given design, element or system or trade life care package as the case may be.

The building's life frame should also be set down in some decision tree format in a systematic way so that those who are involved in the design or life care management have a common life performance scope to move on or work from. Designers must also understand those issues of value and costs and the implications of short term pay back periods in life cycle costing and know how to prepare or develop life care plans.

7 Pre-construction briefing

If sustainable or life buildings are to be achieved, however, the pre-construction stage must also form an integral part of the life design and life planning process. So the pre-construction life briefing needs to be given serious attention.

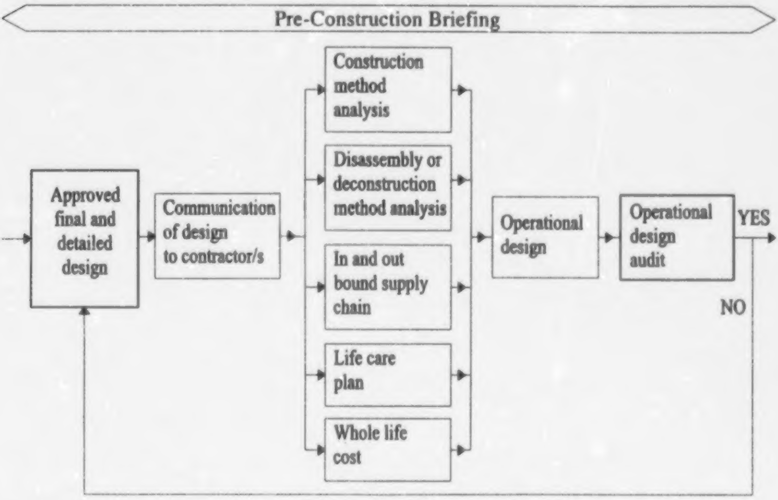

Pre-Construction Briefing
Approved final and detailed design
Communication of design to contractor/s
Construction method analysis
Disassembly or deconstruction method analysis
In and out bound supply chain
Life care plan
Whole life cost
Operational design
Operational design audit
YES
NO

Fig. 4: Pre-construction briefing and design upgrade

As Figure 4 indicates, on the basis of the approved final and detailed design this stage requires a proper grasp of the whole life management including the preparation of the life care plan and the conformance requirements called for in the operational phase. At the same time, the relevant parties would need to be directed to appraise the consequences of service loss of the durability life properties of the materials and components used or to be specified and the building's systems reliability.

8 Performance design reviews

In a quality management system sense the objectives for the design reviews are already established. Nevertheless, to evaluate and validate the transparency of the service life planning, it must itself be based upon the objective evidence made available. Such evidence, must be capable of independent verification or validation, as the case may be. In some instances, those involved in asset management may well contribute from their experiences from across the building portfolio or help improve the life design by acting in an auditing role.

To do so, may mean that the timing and completeness of the terms of reference for the service life planning auditing may have to take place at a number of levels and at several times. Equally, in a legal sense, clients should not however, expect an open season, nor those who act for them. Life design, is not an exact science nor game and some caution must be exercised in the early projects until the databases are sound and experience is gained by all those involved. A learning curve culture will expedite the development of service life design.

Moving on. The operational audit should be such, that the client will know those critical benchmarks and costs for sustaining that life design developed.

At the same time, the trade and design packages should be reviewed within the performance audit for those critical impacts that might threaten that life's design. Here, one might audit the structure, envelopes or performance levels set or review the static systems of the service engineering including their life care planning for access, maintenance etc. Inevitably the extent and detail of the audit activity may range from a broad brush evaluation of a development proposal or concept, down to a given system's life or an elements constituent parts within any stated project or whole life cycle.

The frequency of the design life audit reviews should be established and where relevant, project and product mile stones or agreed bench marks used.

To that end, the established quality management system field should be adopted or modified to suit the way an organisation practices in this field.

Further an attempt to develop within the project quality plan a product quality life care plan might be considered now or be made if were to become part of ISO 15686 or ISO 9000.

9 Conclusion

There must be an understanding that the design vivendi proposed applies equally to new and existing buildings. It should also be clear of the importance of the client and their philosophy and practices to promote life procurement and maintain sustainable life construction. But the need to restructure the design process as intimated in Figures 1-4. must also be in place.

Again both clients and their funders need to find ways to develop life funded, designed and life care managed buildings. Further asset management may need to seek an extended future role, to embrace recovery management and present a view of extending the life of their building through a judicious mix of improving building space management, serviceability and recycling (Wyatt and Gilleard 1994). It is perhaps to those who manage the building stock or asset portfolio and their teams that one should now turn and plead, that they spend quality time in establishing the necessary information that has a significance for life time design, serviceability and improved life care management of their buildings. In a sustainable life sense, one must also include the designed life cycle assessment review for both the incoming and laid up supply chains and their likely waste streams.

Concluding, adopting a 'design for durability' approach should encourage client organisations and their design and project teams to improve the reliability and whole life cost management of their buildings. But, the major players may well tun out to be those involved in life care and building life management and those that fund or insure buildings underpinned by this new vivendi for design for durability with manufacturers offering service life products.

10 References

Cole, R. (1996) Using life cycle assessment as a basis for decision making in building design. *Building & Environment Proceedings BRI.* Warsaw Poland, pp 99-110.

ISO 15686. (1998) *Buildings-service life planning. Part 1: General Principles. Draft for Public Comment.* BSI, UK.

Croce, S., Lucchini, A., Turchini, G. (1992) The control of durability in building components. *CIB World Building Congress Montreal Canada*, n 361

Croce, S., Lucchini, A., Samuelsson, S., Soronis. (1993) CIB W94 Design for Durability, *6th DBMC Conference, Omiya Japan.*

Lucchini, A., Maiellaro, N. (1998) Improving building operators contribution towards sustainability. *CIB World Building Congress, Gavle Sweden.* Symposium A. Volume 1, pp 325-332.

Nireki, T. (1996) Concept of service life into building activities. *Sustainable use of materials durability and sustainable building.* Seminar RILEM & BRE, UK.

Noren, J., Westberg, K., Jenberg, P., Haagenrud, S., Sjostrom, C. (1998) Service life prediction of buildings and the need for environmental characterisation and mapping. *CIB World Building Congress, Gavle Sweden.* Symposium A. Volume 1, pp 379-385.

Scherer, R. (1995) *Product And Process Modelling In The Building Industry.* A.A. Balkema Netherlands, pp 604.

Wyatt, D.P., Soronis, G. (1998) Life cycle assessment and the design agenda. *CIB W96 International Architectural Management Conference.* Brighton, pp 11.

Wyatt, D.P. (1998a) Product life cycle assessment for sustainable building. *Detail Design In Architecture 2.* Ed. S. Emmitt, Publ. BIAT and LMU, pp 10.

Wyatt, D.P. (1998b) Building Product Life Quality. International Scientific Conference Stuv Bratislava. 60 Vyrocie Sekcia Technologia a ekonomika, pp 251-256.

201 IMPROVEMENT OF TRADITIONAL BUILDING MATERIALS AND TECHNIQUES

A.B. Ngowi

University of Botswana, Botswana

Abstract

The pre-industrial societies built their shelters using materials that were locally available. Time was the only means of testing the characteristics of the materials. However, the materials and building solutions that passed the test of time were disseminated throughout the community and were passed from one generation to another through participation in building activities. This ensured dissemination of good practices and created possibilities for improvement. The contemporary societies, on the other hand, have made tremendous breakthroughs in the improvement of strength and durability of materials and structures built using them. While some societies have been able to improve the durability of their building materials and use them to build structures whose life spans can be measured in centuries, other societies are still using the materials in their primitive form with the resulting structures lasting only a few years. Therefore, while the durability of most building materials has improved substantially, the resulting benefits have not reached the majority of the needy societies in the world. Referring to the excellent durability that has been achieved in the modern masonry structures as an example and a case study in Botswana, this paper argues that the only way that the breakthroughs so far achieved in the durability of building materials can be disseminated to the needy societies is by gradually incorporating appropriate elements from the modern practices to the traditional practices in the context of the later. In this way, the skills that have been learned "by doing" will be improved gradually instead of replacing them radically with skills that should be learned from training institutions. The paper concludes by advocating learning from tradition on how to disseminate new findings on building materials for sustainable design.

Keywords: Building materials, contemporary building practices, durability of materials, sustainable design, traditional building practices.

Durability of Building Materials and Components 8 (Volume Three). *Edited by M.A. Lacasse and D.J. Vanier*. Published in 1999 by NRC Research Press, Ottawa ON K1A 0R6, Canada. ISBN 0-660-17742-0

1 Introduction

In the traditional societies, man depended on natural sources of energy and available local materials in forming his habitat according to his physiological needs. Over many centuries, people everywhere appear to have learned to interact with their climate, which shapes the rhythm of their lives as well as their habitat. Thus, using the locally available materials, they built houses that were more or less satisfactory in providing them with the microclimate they needed. The successful solutions to the problems of climate did not result from deliberate scientific reasoning. They grew out of countless experiments and the experiences of generations of builders who continued to use what worked and rejected what did not. They were passed on from one generation to another in the form of traditional, rigid and apparently arbitrary rules for selecting sites, orienting the building, and choosing the materials, building method and design (Mead, 1964; Fathy, 1986). In the traditional construction there was a clear understanding of how the processes of designing, building and operating affect each other, the users and the environment.

While stone is the oldest, most abundant raw building material for both prehistoric and civilized people, brick is the oldest manufactured building material invented by traditional societies. The simplicity, strength and durability of these materials gave them a dominant place in the history of buildings. The small sizes of stone which were made possible by the invention of appropriate cutting tools, and mud bricks, lead to the development of masonry arches and domes which overcame the limitations of spanning long distances (Bowyer, 1973; Beall, 1993).

The Industrial Revolution ushered in innovations in structural building practices based primarily on the classical designs of earlier cultures. The new structural forms, the invention of Portland cement and the development of an efficient steel production process shifted the emphasis from stone and bricks to iron, steel and concrete construction. Moreover, there was a general shift in technological innovation, and skeleton frame construction began to replace load-bearing masonry. However, over years, laboratory and field tests have identified and defined the physical properties of masonry and verified its excellent performance in fire control, sound transmission, sound attenuation and thermal resistance (Beall, 1993).

Today, masonry construction includes not only quarried stone and clay brick but other manufactured products such as concrete block, cast stone, structural clay tile, terra cotta and glass block. Contemporary masonry is also very different from the traditional construction in terms of structural behaviour. Contemporary masonry buildings are thinner, lighter weight, more efficient structural systems and veneers than in the past. In spite of all the achievements in masonry construction, majority of the people in developing countries who depend on earth as their only building material are still using it in its primitive form.

Against this background, this paper discusses the virtues of the traditional construction regarding the durability of building materials and by reviewing the development of soil brick construction in Botswana the paper proposes a framework with which important findings can be disseminated for wider use.

2 Virtues of traditional construction

Traditional construction methods have been able to produce affordable and relevant structures because they developed from their place and inhabitants, the "genius loci", climate, geomophological situation, available materials, hazards, needs for comfort and protection, skills and socio-cultural values and ethnic context and the economic system.

In the traditional European societies, the master mason or master carpenter headed a construction team and he saw the project from a broad picture as well as in detail given the fact that he had administrative skills based on thorough and comprehensive knowledge of the work. He was responsible for procuring materials given his knowledge and experience on the durability of the materials, their sources, cost and the methods of installing them. Knowledge about selection of materials based especially on their durability was passed to all members of the construction team who were in different categories of craftsmen, apprentices or labourers (Galernter, 1995).

In the traditional African societies, construction was an activity for all members of the community. Everyone, including children had a role to play, and through participation, the building skills were passed down from one generation to another. In some parts of Africa, particularly in West Africa, there were families of builders responsible for all the building activities in their communities (Curtin, 1968). Building skills were passed down the generations among the members of these families only. Knowledge about durable building trees that could, for instance, be used for building purposes was passed to children as they accompanied their parents to collect them from the bush. Similarly, methods of making sun-dried bricks in such a way that they attain relatively high durability were explained to the members of the community during their participation in these activities. Thus, whatever knowledge was available, particularly on building materials, it was passed to the members of the community and ultimately to subsequent generations (Kenyatta, 1938; Schapera, 1943; Larsson, 1990; Ngowi, 1997 a).

In the contemporary societies, on the other hand, the construction industry has been split into a maze of specialized roles. The design and construction roles which were successfully undertaken by the master builder in consultation with his client in the traditional European societies or by the members of the community in the traditional African societies, are now often handled by different organizations whose imperatives are not necessarily the same (Ngowi, 1998). The knowledge on the durability of building materials and construction methods, which was common or at least readily accessible, is now restricted to a few materials specialists. Although this specialization has proved itself invaluable in the pursuit of efficiency, its narrow short-range focus, in the absence of a complimentary organic approach, has meant that the breakthroughs that have so far been made on the durability of building materials has not reached the people who need it most. The contemporary societies have certainly something to learn from the traditional construction practices regarding the dissemination of new knowledge on the durability of materials and construction methods to a wider public.

3 Construction using bricks

This section reviews the development of soil brick construction in Botswana as one of building materials whose durability has been successfully improved, and proposes a framework with which important findings can be disseminated for wider use.

The use of bricks for construction dates back to about eight centuries ago. Unlike the stone which occurs naturally and whose suitable deposits are widely scattered, bricks can be manufactured using most types of soil if proper procedures are followed. At first, man found that the most convenient method for constructing earth walls was by pressing mud or clay into conveniently sized lumps and, after air or sun drying, to lay them in walls set in mud mortar. This type of brick is commonly known as "adobe", which is a Spanish word signifying an unburnt brick dried in the sun. Other types of traditional earth construction use rammed earth and pressed earth blocks (Middleton, 1987; Beall, 1964).

However, like building stone, brick must combine properties of durability, low porosity and structural strength with attractive appearance. Many bricks are produced which satisfy one or all of these requirements, but there are three basic varieties: *commons* are suitable for general building purposes, but are not particularly attractive; *facings* are specially made for their attractive appearance which is achieved by variations in colour and surface texture; *engineering bricks* have high strength and low absorption. Each brick needs to have a constant shape and size to simplify bricklaying.

Many kinds of clay material are suitable for making bricks. The material may be pure plastic clay formed from the decay of igneous rock or shale, or it may be alluvium incorporating sand and silt. Four different types of kilns are available for the production of clay bricks: tunnel kiln, continuous chamber kiln, intermittent chamber kiln and the clamp. The main technical aspects of kiln choice are the characteristics of the clay, the scale of output and the available fuels. The choice in these respects is more critical for more sophisticated types of kiln, especially the tunnel kiln, which is by far the most complex of the four (Keddie, 1980). The principle alternative fuels used to fire the kilns are oil, coal and wood. With the dwindling supply of wood in most developing countries and the escalating costs of coal and oil, coupled with unavailability of adequate numbers of skilled and experienced staff, brick production in these countries has remained an expensive undertaking.

4 Soil brick construction in Botswana

Originally, the traditional Tswana house was based on wattle-and-daub construction in which poles were used as structural frame for the walls and for support of the roof (Frescura, 1985). However, the movement of the Tswana people from areas containing ample supply of building trees to areas with less supply, coupled with increase in population lead to abandonment of wattle-and-daub construction and shifted to mud brick walls. Mud brick construction involves manual moulding of the bricks in wooden moulds, after which they are sun-dried before they are used for construction. The walls are constructed by laying the bricks in a bed of cow dung-mud mixture, which is also used to fill the vertical joints and for plastering the walls. Sometimes, sand-cement mortar is used to plaster the walls. Traditionally, the moulding of the bricks, construction of the walls and plastering is done by women.

Although the contemporary types of bricks mentioned earlier, i.e., commons, facings and engineering bricks are available in the formal building materials market, their prices are beyond the reach of the majority of the people living in the rural areas. Also, the skills used to construct the traditional house are not suitable for the contemporary brick. In other words, one has to purchase the materials and hire a trained bricklayer when constructing using the contemporary brick, and this makes the houses expensive. For this reason, the majority of the rural population in Botswana has continued relying on the traditional practice for shelter provision.

However, the traditional house has raised a number of complaints from users who are forced to carry out constant annual maintenance. A study in two major villages in Botswana namely Mahalapye and Tsabong, found that the main problem with the traditional house is concerned with the low durability of the walls due to the effects of rainwater (Ngowi, 1997 b). In order to determine an effective method for improving the wall material, soil samples from the two villages were collected and experimented with various stabilizers. It was established that, the addition of 5% cement by weight to the soil, produced bricks which could withstand the effects of moisture and made water-resistant rendering (Ngowi, 1997 b). The results of this experiment closely matched the findings of a similar experiment that was carried out in the Building Department at the University of the Witwatersrand (Morris and Blight, 1996).

A follow-up study carried out in one of the villages (Tsabong) involved the production of cement stabilized bricks which were used to construct two experimental houses using the traditional skills and labour organization (Ngowi, 1997 c). Three specific measures were taken when constructing the experimental houses:

1. The foundations were set 300 mm below the normal ground level as compared with an average of 100 mm in the traditional construction. The ground surrounding the houses was properly graded to facilitate quick drainage.
2. No rendering was applied to the brick wall. This was done to enable observation of the effects of rainwater on the wall.
3. It was ensured that a house constructed at the same time using unstabilized soil bricks was identified. This would eventually act as a "control" for comparison purposes.

On their completion, the experimental houses were occupied just like the traditional ones without treating them with special care. Their performances, therefore, reflected the real situation.

The following section reports on a study of the performance of the experimental houses and the reactions of the villagers towards the houses two years after their construction.

4.1 The performance of the experimental houses

The assessment of the performance of the experimental houses was based on a comparison with the "control" which was constructed at the same time using unstabilized soil bricks. Although the control was constructed several metres away from the experimental houses on a different plot, it was assumed for all practical purposes to be subjected to similar environmental effects. Also for practical purposes, only the problems affecting the traditional house as seen from the eyes of the user were investigated. These problems included (Ngowi, 1997 b):

1. Undermining of the base of the wall by floodwater.
2. Cracking of the walls and renderings.
3. Water absorption by the wall material when it rains, leading to increased weight and lowering of strength.
4. Separation of the rendering in the form of large panels which eventually fell down.

While the owner of the control said that problem number 1, i.e. undermining of the base of the wall by flood water had affected the structure each time it rained, the owners of the experimental houses said that they never experienced this problem. Personal observations established that, just outside the base of the walls of the experimental houses were flowerbeds, which indicated that the area is never tempered with floodwater. On the other hand, the base of the walls of the control was protected using a 200 mm high plinth, which the owner said is partially washed away each time it rains heavily.

Several cracks were observed on the rendering of the control, but the owner said that no maintenance had been carried out to specifically correct cracking since the house was constructed. No cracks were visible on the experimental houses.

The surface of the rendering of the control showed large notches and scars, which were visibly caused by driving rains. The surface of the walls of experimental houses showed some minor indents and closer examination showed that these might have been caused by presence of large particles in the bricks, which could not withstand the impact of rain and were therefore dislodged.

There was no evidence in the experimental houses to show that the walls had absorbed rainwater. However, the rendering on the control showed uneven surface, which was likely caused by absorption of rainwater and subsequent drying. A combination of cracking and water absorption resulted in some loose portions on the rendering, which on further wetting might fall off.

In general, the owners of the experimental houses said that they were quite satisfied with the performance of the houses and had so far not carried out any maintenance, while the owner of the control complained of the usual constant maintenance. It can, therefore, be argued that the contemporary practice of cement stabilization has benefited the traditional earth construction technology.

4.2 Reaction of the villagers towards the experimental houses

Interviewing the owners of each of the 42 households in Kgosing ward (administrative subdivision of a village), where the experimental houses were constructed assessed the reactions of the villagers. A visit was made to each household in the ward and after introducing the purpose of the visit the following questions were asked:

1. Would you like to own a house similar to the experimental houses? If yes, why?
2. The experimental houses have been here for two years, but you do not seem to have built similar house. What is the problem?
3. What do you think should be done in order to spread construction of such houses more widely?

Question one established that the owners of 36 households who own traditional houses would like to own a house similar to the experimental one because they are affordable and yet do not require regular maintenance. In the remaining six households, there was at least one house in each plot constructed using contemporary materials, and the owners said that they would prefer those houses to the experimental ones. It was interesting to note that all the interviewees were familiar with the cost and procedures used to construct the experimental houses and were all aware of their superior performance compared with the traditional house. Most of this information was said to have been obtained from ward meetings during which ward leaders discussed the virtue of the experimental houses.

Question two established that the 36 respondents who showed interest in the experimental houses had not constructed similar types because they still had sound traditional houses, which had not reached replacement stage. They all indicated that they would replace their traditional houses with houses similar to the experimental ones when time comes.

Question three established three important ways in which the villagers think could be used to spread the use of stabilized soil construction more widely. One proposal, which was mentioned by 30 of the 42 interviewees, is that the government needs to show the villagers that it approves of such houses by constructing similar ones for her employees. Since the government has representation in each ward in the country, such a move was said to be the most effective means for wider dissemination of the method. Another method, which was pointed out by 25 interviewees, is to establish a brigade of builders who will offer guidance to each household that needs to construct a new house. The members of the brigade would undergo a thorough training to ensure that they are conversant with all aspects of stabilized brick construction, and would then offer on-the-spot advice when called upon. A third method which was mentioned by 21 interviewees, particularly women, is that in line with the traditional procedures, workshops need to be conducted regularly in which members of the community, particularly, women would participate and get training on how to construct using stabilized soil bricks.

Based on these responses, it can be concluded that the villagers accept the experimental houses as a solution to the constant maintenance requirement on the traditional structures. The responses also indicate that, given opportunity, the villagers would construct similar houses to replace the traditional ones currently in use. The villagers also expressed their strong belief that the government is in a strong position to make the proposal of using stabilized bricks for construction successful. This is because the government has representation in all the village wards in the country, and by adopting such structures for her employees, the villagers will be assured of the viability of the proposal.

4.3 A proposed framework for promotion of stabilized soil brick construction

With the experience of working with the people of Tsabong and Mahalapye villages, and the responses of the interview conducted in Kgosing ward of Tsabong village, the following framework is proposed as the way of promoting stabilized soil brick construction for wider use:

1. Adequate education of the causes of the problems of the traditional houses should be given to the villagers, and how stabilized soil brick construction may overcome these problems. This education could be carried out at the ward/village level using the existing institutional structures.
2. Device simple procedures for the production of the stabilized bricks and construction of houses based on local traditions. Simple procedures for selection, preparation, manufacturing, stacking and drying of the bricks as proposed by CRATERRE (1987) could form the basis of instructions for the production of the bricks. Also, the use of volume instead of weight batching might be one way of ensuring compliance with the right amount of cement for stabilization purposes.
3. Community management at the village level should strive to encourage members of the community to use the stabilized brick by adopting it for use in community buildings. It has been shown (Ngowi, 1997 d) that such community-managed facilities enjoy the support of all the members of the community.
4. Members of the communities that might benefit from the innovations need to be encouraged to visit the experimental houses and see the virtues of these structures for themselves. This can be done by organizing specific visit from these communities with the aim of learning about stabilized soil construction.

5 Conclusions

This paper has attempted to discuss the virtues of traditional construction regarding the durability of building materials. It then gave a general review of the development of masonry construction from the prehistoric times till now and how innovations in this type of construction could be disseminated for wider use, especially in the needy communities.

The history of stone and brick as the oldest natural and manufactured materials respectively, showed that despite the introduction of more versatile materials such as steel and concrete, and the shift from masonry load-bearing walls to framed structures, they remain the main materials used in the developing countries. The brick has also undergone extensive innovations, which have enabled it to be used in very low cost houses as well as high cost structures. The use of brick construction in Botswana dates back to the 1930s, and has traditionally been used in the sun-dried form, which is laid by women using cow dung-soil mixture. The traditional structure is greatly affected by weather conditions, particularly rainfall, and investigations established that cement stabilization might minimize or completely eliminate the problem.

Experimental houses constructed using cement stabilized bricks showed satisfactory performance two years after construction, but the main issue now is how to disseminate the findings for wider use. A framework for this purpose has been proposed.

It was, therefore, seen that although the contemporary construction has made tremendous improvements on the durability of building materials, it has a lot to learn from traditional construction on how to disseminate new knowledge on building materials and methods.

6 References

Beall, C. (1993) *Masonry Design and Detailing for Architects, Engineers and Contractors*, Third Edition, McGraw-Hill, Inc.

Bowyer, J.(1973) *History of Buildings*, Granada Publishing Ltd., London.

CRATERRE (1987) *Earth Construction Technologies for Developing Countries*, Intermediate Technology Publications, London, 8 vols.

Curtin, P.O. (1968) *Africa Remembered, Narrations by West Africans from the Era of the Slave Trade*. University of Wiscosin Press, Madison, WI.

Fathy, H. (1986) *Natural Energy and Vernacular Architecture*, University of Chicago Press, Chicago, IL.

Frescura, F.(1985) Rural shelter in Southern Africa, University of the Witwatersrand, Johannesburg.

Galernter, M. (1995) *Sources of Architectural Form. A Critical History of Western Design Theory*, Manchester University Press, Manchester.

Keddie, J. and Cleghorn, W. (1980) *Brick Manufacture in Developing Countries*, Scottish Academic Press, Edinburgh.

Kenyatta, J. (1938) *Facing Mount Kenya*, London

Larsson, A. (1990) *Modern Houses for Modern Life*, Wallin och Dahlholm Boktr. AB, Lund.

Mead, M. (1964) *Continuities in Cultural Evolution*, Yale University Press, New Haven, CT.

Middleton, G.F. (1987) Earth-wall Construction, *Bulletin No.3*. Department of Housing and Construction, Canberra.

Morris, J. and Blight, G.F.(1996) Cement stabilization of soil for the Production of Building Blocks, in Dhir, R.K. and McCarthy, M.J. (Eds.) *Appropriate Concrete Technology*, E & FN Spon, U.K, pp. 181-188.

Ngowi, A.B. (1997 a) Virtues of Construction Training in Traditional Societies, *Building and Environment*, Vol.32, No.3, pp. 289-294.

Ngowi, A.B. (1997 b) Improving the traditional earth construction: a case study of Botswana, *Construction and Building Materials*, Vol. 11, No. 1, pp. 1-7.

Ngowi, A.B. (1997 c) A hybrid approach to house construction - a case study in Botswana, *Building Research and Information*, Vol. 25, No. 3, pp. 142-147.

Ngowi, A.B. (1997 d) Community - managed infrastructure facilities, *Facilities*, Vol. 15, No. 12/13, pp. 323-330.

Ngowi, A.B. (1998) Is construction procurement a key to sustainable development? *Building Research and Information*, Vol.26, No.6, pp. 340-350.

Schapera, I. (1943) *Native Land Tenure in Bechuanaland Protectorate*, The Lovedale Press, South Africa.

202 QUALITY CONTROL WITH THE ASSURANCE OF NORMATIVE PRECISION OF GEOMETRICAL PARAMETERS IN ERECTION OF ONE-STOREY FRAMED BUILDINGS

J. Parasonis

Vilnius Gediminas Technical University, Vilnius, Lithuania

Abstract

The reliability of buildings and constructions depends on many factors, including the precision of geometrical parameters of the bearing structures. Already in the stage of design, it is necessary to be able to assess the influence of possible inaccuracies of geometrical parameters on the reliability of bearing structure and the whole building. Over 15,000 control measurements were performed in various towns of the Republic of Lithuania during the erection of one-storey industrial buildings from precast reinforced concrete structures. Using methods of mathematical statistics, the received data have been processed according to separate of geometrical precision parameters in the erection of structures. Statistical data have been accumulated on separate geometrical parameters. The results indicate that actual discrepancies of separate geometrical parameters exceeded permissible norms from 6 to 17 times.

Successful maintenance of buildings with such discrepancies means that the requirements of norms are neither connected with reliable performance of frames of the investigated buildings or with execution possibilities of erection technology. After the investigation of technological processes used in the execution of erection work and of their geodesic provision, it became obvious that certain quality control organization and execution elements need improvement and that the norms of permissible discrepancies are unfounded.

Based on actual distribution of geometrical parameters, on the results of frame element calculations and on calculated maximum permissible values eccentricities, recommended normative discrepancy values of geometrical parameters are presented. The observance of these normative discrepancy values assures that the load of superstructure is applied to columns and their foundations with eccentricities equal or less than maximum permissible ones calculated based on the strength of structures.

Keywords: concrete elements control measurements, erection, precision of geometrical parameters, reliability of building, limits of deviations.

Durability of Building Materials and Components 8 (Volume Three). *Edited by M.A. Lacasse and D.J. Vanier*. Published in 1999 by NRC Research Press, Ottawa ON K1A 0R6, Canada. ISBN 0-660-17742-0

1 Introduction

The reliability of buildings and constructions depends on many factors. First of all, when designing, it is necessary to be able to realise fully and properly the performance of the building appropreate by choosing a corresponding calculation scheme. The actual performance of a bearing structure will always differ from the project-defined one because it is impossible to reach full accordance of a calculated scheme with real performance of a structure. The more so, that joints and loads of separate elements in a calculation scheme are deliberately simplified. Statistical nature of stress-strain properties of building materials and load values also, in its turn, exerts influence on actual performance of bearing structures. Besides, actual performance of a bearing structure is also influenced by the precision of its own geometrical parameters. It is meant that all geometrical dimensions of structures, i.e. their designed geometrical dimensions are established during the designing, however during production, owing to the imperfection of technology, it is impossible to precisely ensure the designed dimensions. So, the actual dimensions differ from the designed ones. Similar process is going on during the erection of buildings and constructions from prefabricated elements: to mount a bearing structure without any deviations, i.e. strictly in project-defined position it is possible only by chance or by wasting a lot of labour and time for the purpose. Therefore, the actual position of bearing structures in a building as well as the geometry of their mutual joints differs from the designed values. It is necessary, therefore, already in the design stage to be able to assess the influence of possible inaccuracies of geometrical parameters to the reliability of bearing structures and the building or construction on the whole. This paper looks into problems linked with reliability assurance during the erection.

Construction norms regulating the precision of geometric parameters in erection of bearing structures contain permissible deviations for separate geometrical parameters. But the practice of construction shows that the limits of deviations are exceeded. For instance, we have investigated the precision of geometrical parameters of one-storey industrial buildings' frames achieved during their erection from prefabricated concrete elements [1]. Having performed over 15 thousand control measurements on objects located in various towns of Lithuania, we found a great difference between the actual and normative precision of geometrical parameters. Part of the investigation results is presented in the figures. Actual deviations of separate geometrical parameters exceeded the permissible ones from 6 to 17 times. As the control measurements were carried out on objects under construction as well on objects in use, successful maintenance of the latter means that the values of permissible deviations are not connected with reliable performance of frames of the investigated buildings. On the other hand, a rather high specific weight (45-80%) of control measurement results, exceeding the permissible deviations, means that the requirements of the norms are neither connected with the possibilities of erection technology. Such practical state of designing, construction and maintenance of one-storey industrial buildings needed a thorough and detailed investigation [2].

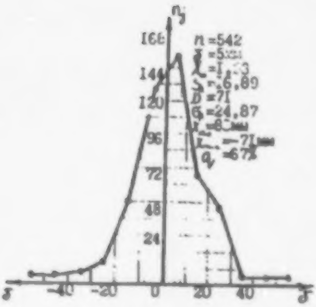


Fig. 1: Column deviations from building axes in lower section in traverse direction of the building

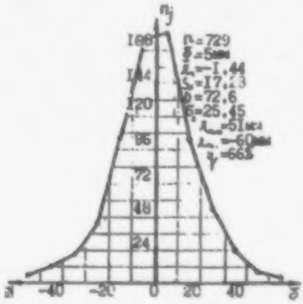


Fig. 2: The same, but in longitudinal direction of the building

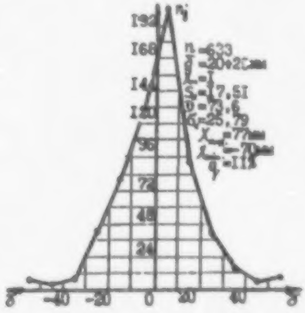


Fig. 3: Column deviations form building axes in upper section in traverse direction of the building

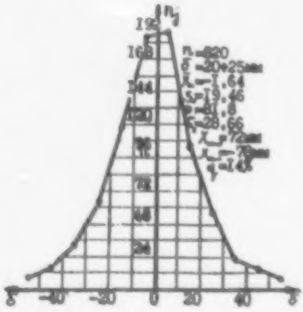


Fig. 4: The same, but in longitudinal direction of the building

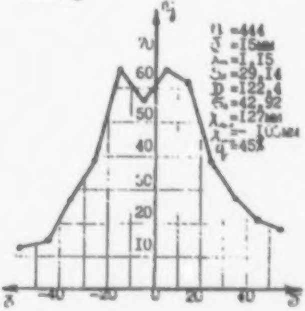


Fig. 5: Deviations of supporting lengths of truss structures on inner rows of column

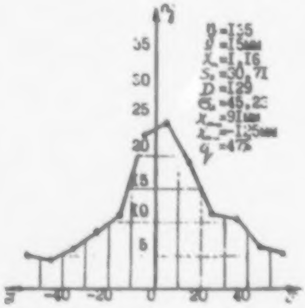


Fig. 6: The same, but on outer rows of column

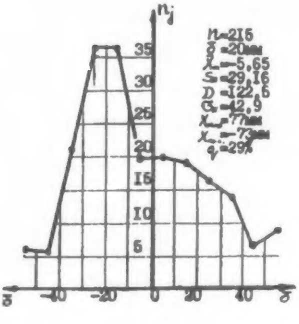


Fig. 7: Deviations of span ends between truss structures

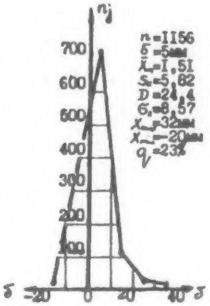


Fig. 8: Deviations of cross-section dimensions of columns

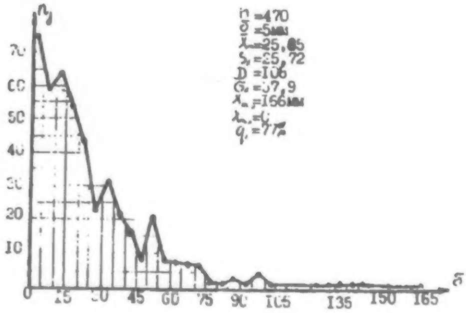


Fig. 9: Deviations of longitudinal axes of truss structures from the axes supports

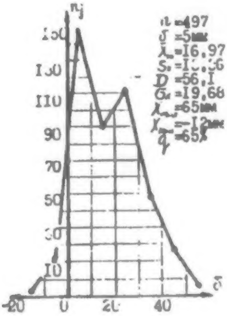


Fig. 10: Cross-section width deviations of truss structures

Legend:

n = number of control measurements
δ = value of permissible normative deviation
x = average data of actual data
S = root-mean-square deviation value of actual data
D = dispersion of actual data at 4% defectivity level
σ_x = root-mean-square deviation level
q = specific weight of control measurement results exceeding permissible deviations, percentage

We have investigated execution processes of erection technology and their geodesic provision and also analysed the requirements of normative documents regulating the erection works and found that various requirements of normative documents are not coordinated among themselves and that a number of elements of geodesic provision of erection works need improvement [1].

It has been established that the main cause of inferior quality of construction production is the lack of operational site inspection. Even the requirements of normative documents set for erection works are oriented for the fixation of the final result. Geodesic execution surveys are made up upon the completion of building erection. Practical use of such surveys consists only in the fact that without them the customer won't accept the building for maintenance. That's why they are drawn up formally, and the entered data in most cases does not correspond to reality [1]. This, of course, does not mean that erection works are carried out by eye, i.e. without using the necessary geodetic instruments, but the results of control measurements mentioned above indicate that geodesic provision of erection works is unsatisfactory and the technology of their execution is imperfect.

In order to avert the effects caused by the shortcomings of erection technology and its geodesic provision, new state norms [3] have been prepared after the completion of the investigation. The principal emphasis of the norms is laid on the execution of site operational inspection and on keeping of documentation necessary for this stage of works. It was necessary to determine the parameters of geometrical precision to be checked and criteria for their assessment in a concrete stage of erection works (separately: 1 - for the mounting of elements in project-defined position and their temporary fastening; 2 - for final fastening of elements in project-defined position). The geodesic execution surveys according to the requirements of the new republican norms are to be drawn up during site operational inspection and later, when handing over the object for maintenance, presented to the customer. This considerably changed the situation for the sake of quality because the geodesic check-up is performed during site operational inspection with simultaneous entering of the results into the geodesic execution surveys. This calls forth to achieve the necessary precision of geometrical parameters during the erection process; not just fixing of the actual situation at the final stage of construction when any alterations are either impossible or they call for considerable expenditures. In other words, precision assurance of geometrical parameters during erection has become a controllable process.

It became clear during the investigation that the precision of geometrical parameters also greatly depends on the methods of geodesic works. It turned out to be that the settled technology of geodesic provision for erection works linked the precision of many parameters with the axes of the building. This can be justified for substructure works, but in erection of superstructure of a building it often leads to the accumulation of errors. For example, when in erection of a column, its base is aligned with the axes of the building, then, owing to inaccuracies in the construction of foundations, they are loaded with certain eccentricities. Later, when erecting truss elements and again trying to align their longitudinal axes with the axes of the building, the truss elements, due to inaccuracies in the erection of foundations and columns, are shifted from the axes of columns, so the roofing loads are transferred to the columns with additional eccentricities. It is obvious that, first of all, it is necessary to try to carry out the substructure operations as accurately as possible, especially when mounting the foundations. But then, when erecting the columns, it is necessary to align their axes with the axes of foundations, but not with the axes of the building. Later on, the axes of the truss elements should also be aligned with geometrical axes of columns, but not with the axes of the building. The mentioned peculiarities found their reflection in the new state norms [3].

However, in order to assure the reliability of a building in stage of its erection, it is very important to have sound values of permissible deviations. They must be linked with carrying capability of the structures and with technological precision of the erection process. Apparently, the lack of corresponding actual data is the reason that this aspect has not been taken into consideration before.

The assessment of assurance reliability of limit deviations stated in the norms regulating the execution of erection works by comparing them with actual distributions of geometrical parameters achieved in erection indicated that assurance reliability of random eccentricities caused by roofing load on columns as well as of random eccentricity values transferred to foundations in most cases is very low. The application of the above-mentioned organizational and methdological means gives a noticeable increase of reliability, but in case of columns it often remains rather small.

In the investigated cases, i.e. for roofing load effects on columns (or for the alignment of reference points of permissible deviation when mounting truss structures on columns) as well as for the transfer of loads to foundations (or for the alignment of reference points of permissible deviation in lower section of columns and vertical deflections of columns in their upper section), it is possible to make use of the relationships defining how a random point ($\tilde{e}^2_{O_x}, \tilde{e}^2_{O_y}$) can get into a certain limited zone on the plane. These relationships are known from the two-dimensional normal distribution law of the probability theory.

The analysis of actual distributions of geometrical parameters [2] shows that the parameters of truss element mounting on columns are near to ellipse and the parameters of column erection - near to circle. We suggest, therefore, to use corresponding relationships for the determination of permissible discrepancies:

$$\frac{e^2_{O_x}}{\sigma^2_{e_{O_x}}} + \frac{e^2_{O_y}}{\sigma^2_{e_{O_y}}} = k^2 \qquad (1)$$

If the semiaxes of the ellipse are proportional to the values of root-mean-square discrepancies and its centre coincides with the origin of coordinates (i.e. $\tilde{e}^2_{O_x} = \tilde{e}^2_{O_y} = 0$), then the probability of random point ($\tilde{e}^2_{O_x}, \tilde{e}^2_{O_y}$) getting into ellipse B can be expressed as:

$$P\left\{\left(\tilde{e}^2_{O_x}, \tilde{e}^2_{O_y}\right) \in B_k\right\} = 1 - e^{-k^2/2} \qquad (2)$$

The probability that a random point ($\tilde{e}^2_{O_x}, \tilde{e}^2_{O_y}$) will get into circle C with radius r can be expressed as:

$$P(r) = 1 - e^{-r^2/2\sigma^2_m} \qquad (3)$$

Logarithming expression (2) and (3), we correspondingly receive:

$$k = \sqrt{-2\ln(1 - P)} \qquad (4)$$

$$\sigma_{e_0} = \frac{r}{\sqrt{-2\ln(1-P)}} \tag{5}$$

By choosing probability (P), expressing the probability for a random point ($\tilde{e}^2_{O_x}, \tilde{e}^2_{O_y}$) to get into the ellipse or the circle, the values of k and e can be found from (4) and (5). And then, the limit values of permissible eccentricities can be received by using the actual values of root-mean-square discrepancy [1].

Basing oneself on the data of actual distribution of geometrical parameters, the results of frame element calculations and calculated values of permissible limit eccentricities were calculated and entered into a Table . Recommended Normative Values of Limit Deviations of Geometrical Parameters in Erection. These values define the reliability of columns and foundations. If the values of limit deviations presented in Table 1 are not exceeded, then roofing loads to columns and column loads to foundations are transferred with eccentricities which are equal or less than the permissible limit ones. The values of permissible limit eccentricities were calculated based on bearing strength of structures.

Table 1: Recommended normative values of limit deviations of geometrical parameters in erection

Parameters	**Limit Values of Deviations (mm) for Certain Existing Reliability of Eccentricity Values before and after the Implementation of the System of Precision Assurance Means**			
	0.985		0.96	
	before	after	before	after
1	2	3	4	5
Alignment of reference points of foundation trenches with the axes of the building	34	20	30	18
1	2	3	4	5
Alignment of geometrical column axes in lower section with geometrical axes of foundation trenches	34	14	30	10
Deviations of geometrical axes of columns from vertical line at the upper section	10	5	8	5
Symmetry deviations of supporting lengths of truss (subtruss) elements in span direction on inner rows of columns	40	20	30	15
Deviations of longitudinal axes of truss (subtruss) elements from the axes of supporting lands	10	5	10	5

2 References

Parasonis J. (1991) The Assurance of Precision of Geometrical Parameters in Erection of Precast Reinforced Concrete Structures. -Vilnius, Lithuanian Academy of Management, 188 pgs. (in Russian)

Parasonis J. (1995) The Reliability of Frames of One-Storey Industrial Buildings with Precision Assessment of Geometrical Parameters in Erection. -Vilnius, Technika, 392 pgs. (in Russian)

RSN 118-89. (1990) Guidelines for the Assurance of Precision of Geometrical Parameters in Erection of Frames for One-Storey Industrial Buildings. -Vilnius, Lithuanian State Committee for Construction, 32 pgs. (in Lithuanian)

203 DESIGN FOR DURABILITY — A PRACTICAL APPROACH

E. Robertsen

Narvik Institute of Technology, Narvik, Norway

Abstract

Today's building practice has led to a lot of premature failure and lack of durability, which can cause serious safety, serviceability and functional problems. Traditionally design for durability has been performed in an empirical, often unstructured manner based upon implicit durability requirements. A new approach, which ensures that materials and components are suitable and will perform satisfactorily during the intended life, is necessary. Service life estimations are complex and information intensive. In spite of scientific imperfections and lack of information on right format, there is a need for the practical engineer to start using the accessible knowledge. The suggested framework for service life based design, construction and management of building assemblies will ensure that performance requirements are fulfilled during the design life, allows optimisation of the whole life cost of buildings and permits life cycle assessments. The service life influence in different phases, from client's brief till demolition or major refurbishment, can be assessed in five consecutive stages; conceptual design, modelling and prediction, engineering stage, construction and in service period. The target design life must be determined in an early design stage and will serve as a basis for materials selection, detailed design, execution procedures and maintenance strategy. After predesign the gradual deterioration induced by the interaction between alternative materials and the actual surrounding environment can be estimated. Different approaches can be used for predicting the future behaviour. Models must be based upon a clear phenomenological understanding of the degradation process. In the engineering stage materials selection, detailed design and a quantitative description of products and procedures are executed. In the construction period key factors for durability will be quality assurance of solutions and execution procedures including environmental control. The degradation process and thereby the obtainable service life in terms of performance can in the service period be controlled through adequate operation-, inspection-, maintenance- and repair activities.

Keywords: service life, durability, design life, modelling, execution, maintenance

Durability of Building Materials and Components 8 (Volume Three). *Edited by M.A. Lacasse and D.J. Vanier*. Published in 1999 by NRC Research Press, Ottawa ON K1A 0R6, Canada. ISBN 0-660-17742-0

1 Introduction

The construction industry is currently experiencing numerous envelope problems and premature material breakdown. Failure is often rooted in misunderstanding of the particular requirements, improper initial design, defective installation, or a disregard for the need to provide routine and regular maintenance. Failure or level of service less than expected can result in serious adverse consequences to building value, operational costs, occupant comfort or environmental impact. The functional failure rate of building assemblies will often follow a bathtub curve as illustrated in figure 1. The simple total failure rate may be considered as the sum value of three imaginary components. The first part is caused by deficiencies in planning and construction not attended by the quality system. Number of premature failures will gradually decrease. Another cause of deficiencies is sudden deterioration caused by random events like fire and earthquake. The probability of such failure can be seen as constant during the service life, and will not be treated further in this paper. The third component is the gradual deterioration induced by the interaction between the material and the outdoor environment combined with in use influence.

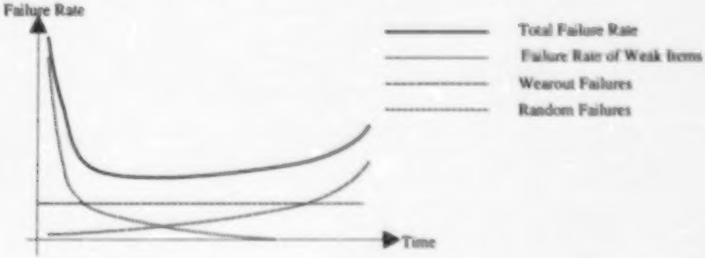


Fig. 1: The Bathtub Curve illustrates the probability of failure over time

The envelope of modern buildings is subjected to higher stresses than were those of earlier buildings. New and increasing demands impose new constraints, which combined with the increasing variety of materials, systems and assemblies make construction and prediction of performance considerably complex. Service life can be defined as the period of time all essential performance characteristics of a properly maintained item in service exceeds the minimum acceptable values with reasonable economy. The service life limit can be both technical, economical, functional or aesthetic. Service life predictions are needed whenever a new material without a significant performance history or exposure to new environmental exposure is proposed. Despite the sparse information available it is in many cases possible to make reliable service life predictions for the progressive degradation of materials, components and assemblies due to environmental exposure based on sound knowledge of degradation mechanisms and kinetics of degradative reactions in the actual service environment. Prediction of service life is however a highly complex issue as it require detailed information in all life stages. A major problem is that performance- and service life data are too scarce or on a wrong format to provide adequate input to service life analyses. Through a systematic consideration of all factors affecting serviceability of assemblies, components and materials it is however possible to give a reliable forecast of service life, required maintenance, and thereby the cost of building ownership. Collecting and analysing of input data for service life predictions are expensive and time-consuming activities.

2 Conceptual design life

The service life influence in case of progressive degradation due to the environmental exposure, can be considered in five consecutive stages;

- 1.Conceptual Design Life
- 2. Predesign, modelling and prediction
- 3. Engineering stage
- 4. Construction period
- 5. In service period

The design life can bee see as the period of use for a product, a component, an assembly or a construction intended by the designer. The target design life must be determined in an early design stage and will serve as a basis for materials selection, detailed design, execution procedures and maintenance strategy. The design life of the building (DLB) as a whole must be specified according to the actual building category and main construction system. After a conceptual design phase materials, components and assemblies are classified in permanent, exchangeable or maintainable parts. The expenses and difficulties in replacement must be estimated when the different parts are classified as life long, replaceable or maintainable. For each part the performance requirements are listed and a target design life for components and assemblies (DLC) are specified in classes based on functional requirement, cost and accessibility (ISO/DIS 15686, 1997).

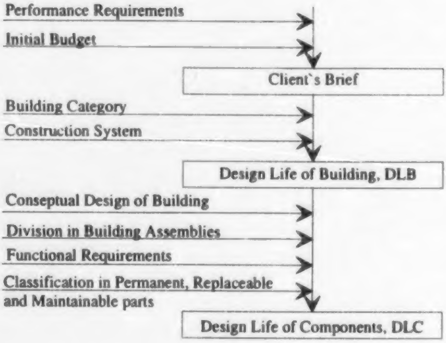

Performance Requirements
Initial Budget
Client`s Brief
Building Category
Construction System
Design Life of Building, DLB
Conseptual Design of Building
Division in Building Assemblies
Functional Requirements
Classification in Permanent, Replaceable and Maintainable parts
Design Life of Components, DLC

Fig. 2: Schematic illustration of input parameters in design life determination

Each component is assigned a design life used as a planned time for replacement or major repair. If the correct predicted damage is less than corresponding to the performance limit, the required design life can be maintained and the cost of maintenance and repair can be estimated. The suggested design life of building and inaccessible or structural components is 10 to 150 years, while major replaceable components may have a design life (DLC) up to 40 years (ISO/DIS 15686, 1997). Where replacement is expensive or difficult DLC could be up to 100 years. The recommended design life for service installations and external cladding is normally 10 to 25 years.

3 Predesign, modelling and prediction

Components and assemblies are given a preliminary design based on the fixed design life in accordance with the principle of parallel service life, where no layer with longer design life must be dismantled for maintenance or replacement of another layer. Based on overall judgement materials limitations are recommended. Material selections are based upon functional, technical, economical, environmental and aesthetic requirements. The requirements must be satisfied both initially and during the design life. Deterioration of building materials often occurs as a result of chemical or biological processes combined with physical action. Chemical composition and microstructure of the material thus determines the durability for a given exposure. Today's macro level durability design are based on simple «deemed to satisfy rules» on a structural level. Instead durability can be quantitatively expressed as service life based on a materials engineering level using simplified service life models, or on more or less correct micro-level physical/chemical models for degradation and environmental actions on a materials science level. Different models with unequal complexity and accuracy are thus available. Appropriate level depends on the intended service life, degradation mechanism, the severity of the exposure condition, consequences of failure and accessible knowledge. Among sources of service life data are historical reference service life data, benchmark level of specifications with «insured life» and adjustment factors like the HAPM component life manual (HAPM, 1997) and the proposed ISO factorial system, use of expert judgement or different deterministic or statistical prediction models. The nature and progression of deterioration mechanisms are of main interest in models for reliable service life predictions. For mathematical modelling all functional requirements must be expressed quantitatively in terms of measurable material properties. For high reliability the service life methodologies must be based upon a clear phenomenological understanding of the degradation process, and be able to identify degradation mechanisms which are sensitive in means of that only minor changes in materials or climate may cause severe damage to the materials. For mathematical modelling on a material scientific level the following are needed for high reliability;

1. Quantitative expression of functional requirements in terms of quantifiable, measurable parameters such as stress, strain, area reduction, loss of mass, temperature, moisture content etc. included limit states for functional level (end of life criteria)

2. Environmental description in quantitative terms on a micro level as a function of time
3. Material data included transport coefficients which allow prediction of the time dependent concentrations and temperatures as a function of depth from the surface
4. Detailed phenomenological understanding of all deterioration mechanisms that may occur in the specific material-environment combination
5. Knowledge of deterioration rate based upon theoretical considerations, exposure or empirical data
6. A maintenance strategy plan with service life effects

The service life prediction can partly be based on verifiable data such as material properties, geometric design and surface treatment, but must also rest on assumptions of execution level, environmental exposure, in use conditions and effect of maintenance efforts. Quality assurance must ensure that prediction assumptions are satisfied during engineering, execution and use if the service life management is to be credible.

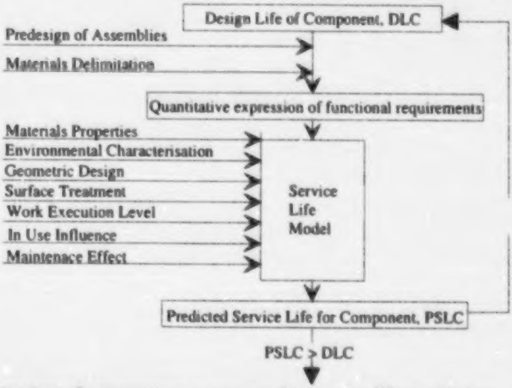

Design Life of Component, DLC
Predesign of Assemblies
Materials Delimitation
Quantitative expression of functional requirements
Materials Properties
Environmental Characterisation
Geometric Design
Surface Treatment
Work Execution Level
In Use Influence
Maintenace Effect
Service Life Model
Predicted Service Life for Component, PSLC
PSLC > DLC

Fig. 3: Illustration of parameters necessary for service life prediction

Under RILEMS`s direction a general framework for service life prediction based upon a combination of field investigations and laboratory testing has been prepared (Masters & Brandt, 1987). In addition to the generic standard methodologies there is a need for specific guidelines for service life prediction for different building materials. The deterioration process may occur gradually, with or without delay, cyclically (as with seasonally effects) or as a stepwise change under extreme environmental loads or combinations of loads. For some individual deteriorating mechanisms a number of several different service life models are available, examples are models for service life estimation for corrosion of reinforcement in concrete and dose-response functions for different metals. For other mechanisms present knowledge is too scarce to build models. Knowledge of and ability to characterise the exposure condition on a microclimate level are today a major obstacle for service life modelling. In many practical cases materials are exposed simultaneously to different deterioration factors leading to synergy effects where the combined effect is worse than the sum of the effects of the individual mechanisms. Service life models for interactions between several deterioration mechanisms are modest available.

Service life management in building industry requires easily accessible mathematical service life models and input data on right format. Description of degradation given in scientific documents for limited objectives is often rather complicated to extract. Service life modelling must to some extent rest on previous experience, collected as standard service life data like the HAPM Component Life Manual (HAPM, 1997). Collection and analysis of historical life time data are time consuming since data often are stored in a unstructured way in maintenance sources. Use of historical data has limitations for practical service life estimations due to changes in material properties, execution techniques and unknown exposure history. In service life prediction historical data must be combined with expert judgement based on knowledge of the underlying failure mechanism.

The service life for a number of presumptive identical parts will vary due to the variations in material properties and exposure condition (Robertsen, 1996). Depending on the intended use, recognising the uncertainty's associated with deterministic testing and modelling, service life safety factors may be established based on the consequences of failure. Recognising the stochastic nature of variables in service life predictions, a probabilistic approach is needed if the uncertainties in the prediction are to be properly assessed. The service life can then be presented as the intended service life period where the limit states may, with certain reliability, not be reached within the design life or as lifetime where the reliability is related to the probability that the design life is exceeded.

4 Engineering phase

The main objective in the engineering stage is to prepare for safe, functional, economical and durable constructed facilities in the context of sustainable development. The prediction of performance, both initially and during the service period, is an integrated part of the design process. For structural design available quantitative data enables designers to reach fairly precise conclusions regarding structural performance. This is not the case with durability. An assessment of service life is however in most cases possible by equating required performance level to predicted functional level. Based on the preliminary design and service life estimations for alternative materials and solutions which meet the functional requirements, both initially and over time, an economical optimisation can be executed based on life cycle cost, LCC. In the same way a life cycle assessment, LCA, of the alternative solutions can be carried out.

The service life is directly related to the design efforts. It is insufficient and risky to merely copy details from previous projects without considering the surrounding environment. Prescribed solutions must be based on detailed analysis of the performance requirements for the actual component as a basis for service life modelling for the interaction between the material and the exposure condition. In the engineering stage detailed geometric design and materials specifications are outlined. Modern materials are designed to satisfy a multitude of specific functions. Individually their performance characteristics tend to be reasonably predictable, the designers challenge is thus to predict the behaviour of the complete assembly, both initially and over time. For each component and assemblies the future maintenance, repair and replacement needs must be identified, and the impact of any repair and replacement options upon future performance and service life must be considered.

Building design is a creative process aiming to create optimum solutions by detailed comparison of alternative possibilities. Also health, environment and security aspects must be considered, both in the construction period, in the permanent service stage and under demolition. Connected materials must be chemically and physically compatible, and detailing, lead-troughs, joints, and tolerances are to be accommodated. Connections between adjacent parts are often critical to the overall performance for assemblies. The geometric design must minimise accumulation of moisture and other degradation factors and permit accessibility for execution, cleaning, maintenance and replacement. The written specifications and drawings must meet the performance requirements, be technically, economically and environmentally optimal, in accordance with national building regulations and must undergo quality assurance.

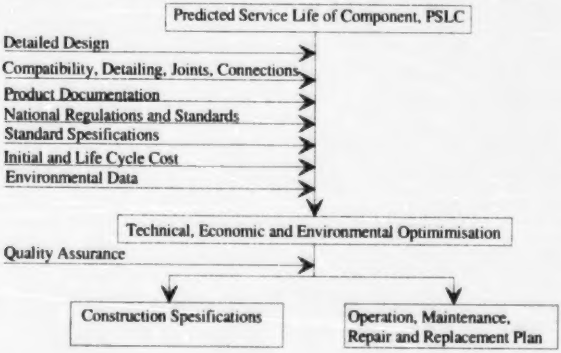

Predicted Service Life of Component, PSLC
Detailed Design
Compatibility, Detailing, Joints, Connections
Product Documentation
National Regulations and Standards
Standard Spesifications
Initial and Life Cycle Cost
Environmental Data
Technical, Economic and Environmental Optimimisation
Quality Assurance
Construction Spesifications
Operation, Maintenance,
Repair and Replacement Plan

Fig. 4: Illustration of input necessities for engineering optimisation

5 Construction period

The potential functional levels and service life for the different assemblies are determined in the engineering stage by material selection, geometric design and chosen surface treatment. The contractors primary task is to execute the described solutions in accordance with good workmanship. The functional requirements must be analysed in order to detect critical points and procedures. The information turnover between different participants in the consecutive stages in the building process is a key factor in order to fulfil performance requirements. Execution of complex building assemblies and connections with expected service life are secured by detailed specifications, use of formerly well educated personnel and adequate quality assurance. As with design the result considerably depends on the competence and engagement of persons involved in the process. As far as possible verified standard solutions and execution procedures shall be used. The site organisation, management, process equipment, project economy and time available will influence on the workmanship level and thus the functional level for components and assemblies. Satisfactory storage of materials and protection of manufactured assemblies are necessary to prevent premature deterioration and damage. While building envelopes are designed to withstand a particular environment and its attendant conditions, insufficient recognition is given to the environmental conditions that exist during the construction phase and the effect they have on the durability of building components. Climatic restrictions and precautions for different parts have to be listed in the specifications.

Trough design, modelling, engineering and construction the initial quality and thus the potential installed service life for components and assemblies are set. If the potential service life after construction not exceed the design life, precautions are to be done. This can imply technical improvements as replacement, repair and surface treatment or economical compensation for future expenditure du to reduced service life. After completion of the construction work as-built documentation must be added to the operation, maintenance, repair and replacement plan.

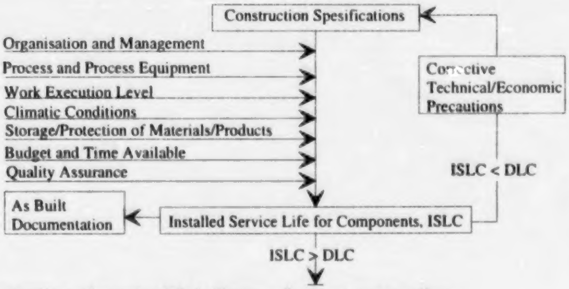

Construction Spesifications
Organisation and Management
Process and Process Equipment
Work Execution Level
Climatic Conditions
Storage/Protection of Materials/Products
Budget and Time Available
Quality Assurance
Corrective Technical/Economic Precautions
ISLC < DLC
As Built Documentation
Installed Service Life for Components, ISLC
ISLC > DLC

Fig. 5: Illustration of service life influence during construction

6 Use

The effort to obtain optimal performance does not end once a part has been constructed. After installation strains from environmental exposure, use and internal incompatibility will gradually reduce the functional level for materials, components and assemblies. Through adequate operation-, maintenance- and repair activities it is possible to control the degradation processes and thereby the reduction in functional level so that the design life can be reached. The challenge is to identify the degree, quantity and appropriate timing of corrective and remedial action, and the influence of different actions in terms of service life.

The in-service period can from maintenance perspective be divided into three phases, as figure 1 illustrates. In the guarantee period building deficiencies are detected and repaired. The ordinary in-service period is characterised by planned activities in accordance with the maintenance strategy plan. Towards the end of the service life failure frequency, and thereby necessary maintenance efforts will increase. In the engineering stage a maintenance strategy and a maintenance plan based on preventive actions and replacements are worked out. In addition minor defects must be repaired.

Combined planned and response maintenance are essential to ensure satisfactory performance for the whole design life.

Through the in-service period condition assessment has to be worked out periodically. Destructive and non-destructive assessment methods must be combined. The inspection, manual or performed by condition monitoring, may be performed on demand, at predefined intervals or on a continuos basis. Different concepts have been used to describe the condition of a system at the time of inspection. Among these are performance indicators, true condition and health monitoring (Reinertsen, 1997). The assessed condition is to be compared with the predicted condition at the actual time. Corrective actions necessary if the service life shall exceed the design life can thus be foreseen. The service life ends when technical, economic, functional or aesthetic requirements no longer are fulfilled. The component or assemblies are then to be downgraded, repaired or demolished.

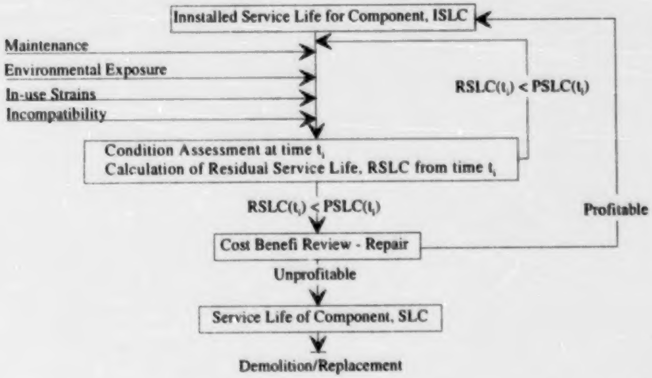

Innstalled Service Life for Component, ISLC
Maintenance
Environmental Exposure
In-use Strains
Incompatibility
RSLC(t_i) < PSLC(t_i)
Condition Assessment at time t_i
Calculation of Residual Service Life, RSLC from time t_i
RSLC(t_i) < PSLC(t_i)
Profitable
Cost Benefi Review - Repair
Unprofitable
Service Life of Component, SLC
Demolition/Replacement

Fig. 6: Schematic illustration of service life management in the in-service period

7 Conclusions

Building materials and components have finite service lives due to gradually chemical, physical or biological degradation, which reduce the ability to perform as required. This gradual deterioration can be modelled and a quantitative service life predicted. The service life modelling covers only gradual deterioration, not obvious deficiencies in engineering and execution, nor suddenly destruction. Service life modelling allows technical and economic optimisation in durability design and permits life cycle assessment. In this paper the rudiments of an integrated design-, construction and management strategy to control service life for building component and assemblies has been suggested. The methodology implies that all factors affecting service life in programming, design, construction and maintenance phases are systematically considered. In an early design stage the service life target for each component is set as a basis for durability design. Reduction in performance is predicted through mathematical modelling of the deterioration processes. In the service life period the real functional level at the time of inspection is to be compared with the predicted level. The service life can then be controlled by adequate maintenance to exceed the design life. The new quantitative durability design approach is complex and information intensive as it requires detailed knowledge of all factors affecting service life. Despite imperfections in methodologies and available data it is today in many cases possible to predict service life with reasonable accuracy. If the building industry starts to use a systematic methodology for service life estimations best practice in optimising performance criteria will be developed further together with necessary input data.

8 References

Architectural Institute of Japan (1993): Principal guide to service life planning of buildings, 75 p.

British Standards Institution (1992): BS 7543: Guide to durability of buildings and building elements, products and components. BSI, London, 43 p.

Bomberg, M. & Allen, D. (1996): Use of Generalized Limit States Method for Design of Building Envelopes for durability. *Journal of Thermal Insulation and Building Envelopes*, vol. 20, July 1996, pp 18 - 39.

Canadian Standards Association (1995): S478-95: Guideline on durability in buildings, 93 p.

Fagerlund, G. (1985): Essential Data for Service Life Prediction. *Problems in Service Life Prediction of Building and Construction Materials*. Martinus Nijhoff Publishers, 1985, pp. 113 - 138.

Frohnsdorff, G. (1996): Predicting the Service Lives of Materials of Construction. *Proceedings of the 1996 4th Materials Engineering Conference*, Washington DC, USA, pp. 38 - 53.

HAPM Component Life Manual (1997), E & FN Spon, London.

Holmes, R. (1994): Built asset management practice. CIOB Handbook of facilities management. *Longman Scientific & Technical*, 1994, pp.137 - 154.

ISO 15686 Part 1 (1997): Buildings: Service Life Planning, Part 1 - General Principles, ISO TC59/SC3/WG9 Draft, 1997, 59 p.

Lacasse, M. A., Vanier, D. J. (1996): A Review of Service Life and Durability Issues. *Durability of Building Materials and Components*, Stockholm 19-23 May 1996, pp. 857 - 864.

Masters, L. M., Brandt, E. (1987): Prediction of service life of building materials and components. *Final report CIB W80/RILEM 71-PSL*, Paris, 23 p.

Nireki, T. (1996): Service life design. *Construction and Building Materials*, Vol. 10, No. 5, pp. 403-406.

Reinertsen, R. (1997): Health condition and residual life of deteriorating technical systems. *Doctoral Thesis, Norwegian University of Science and Technology*, Trondheim, 130 p.

Robertsen, E. (1996): Service Life for Building Envelope. *Report (in Norwegian)*, Narvik Institute of Technology, 1996, 74 p.

Siemes, A. J. M. (1996): Framework for a procedure for design for durability. *Durability of Building Materials and Components*, Stockholm 19-23 May 1996, pp. 1175 - 1184.

204 OPTIMISATION OF THE LIFE SPAN OF BUILDING COMPONENTS

H. Tempelmans Plat

Eindhoven University of Technology, Eindhoven, The Netherlands

Abstract

The optimal life span of a building component depends on a full-cost analysis, including environmental consequences at the moment of new construction and demolition. Balancing of various cost consequences and the comparison of competing technical solutions needs a transformation on an annual basis. Reducing annual costs may be effectuated by lengthening of the life span by introduction of flexibility; i.e. reuse of components in different positions. This needs a split up of adaptation into decomposition and installation costs. The choice out of technical solutions is only possible when a functional demand period scenario is available for the services to be generated by the building as a set of technical solutions.

Keywords: Demand definition, open building, economic life span, choice criterion

1 Introduction

In the development of building components, the focus is primarily on minimisation of total costs (incl. environmental consequences) over the technical life span. However, the usable period often is much shorter, resulting in relatively higher costs. Since the competing solutions (out of which has to be chosen) have different life spans, the time factor in comparison should be clear; i.e. the same period of comparison.

The usable period most of the time is determined by the demand for the services for which the component will be used. Materials and components can be used as a technical solution in an exploitation process in which a heterogeneous flow of services will be generated. This can be realised by means of flexibility of a building as a set of technical solutions. The usable life can be extended, resulting in relatively diminished cost consequences.

Durability of Building Materials and Components 8 (Volume Three). *Edited by M.A. Lacasse and D.J. Vanier*. Published in 1999 by NRC Research Press, Ottawa ON K1A 0R6, Canada. ISBN 0-660-17742-0

Focus in this paper will be on the dimension time in demand definition and the factors which have to be clear to result in a full-cost analysis and information needed to decide about the use of flexibility.

2 Optimal life span

Life spans of buildings or building components often are overestimated (Tempelmans Plat 1982) and as a consequence they are demolished (not as an exception) before half of the potential service life (Wyatt 1994). On the other hand, individual investors have a very short period of (financial) interest (Tempelmans Plat 1986) not taking any extension of a life span by reuse or recycling into account (Hill et al. 1994).

The criterion for an optimal life span has to be defined, as well as the information needed as a basis for decision-making. Figure 1 illustrates that several technical solutions in general are available to fulfil the individual or market demand for services. The solutions may differ substantially in life span but supply (usually in co-operation with other components) the same services according to well-defined performances. (Tempelmans Plat 1998)

The economic life span is by definition equal to or shorter than the technical life span, but usually equal to the demand period. In some cases the technical solution will be replaced identically in order to fulfil demand over the functional demand period. This functional demand period may equal to the individual demand period in case of very specific demand or to the market demand period when subsequent users may be expected to benefit from the supply of the flow of services.

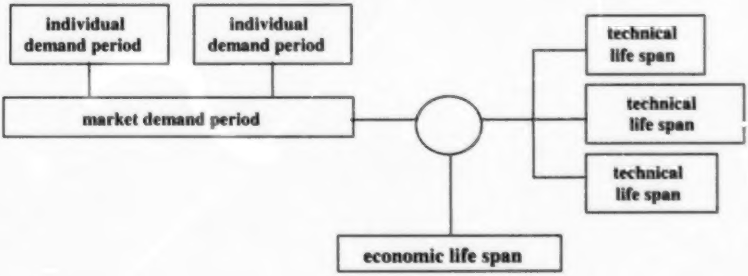


Fig. 1: Economic life span as optimum between functional demand period and technical life span of the most appropriate technical solution

All costs to be taken into account to decide about the technical solution as well as the appropriate economic life span have to be defined and made comparable.

3 Full-cost consequences

The sacrifice to have a technical solution or the resulting services available over the estimated life span is usually measured in monetary terms. We have to deal with full-cost and real-cost-prices (Hill and Bowen 1997) in order to decide about a choice which really minimises the environmental consequences.

By real-cost-prices is meant that prices really reflect scarcity. So, the long-term effect of, e.g., using exhaustible resources should be incorporated in the price to be paid at the moment of use of the source. Only in this way all consequences of the choice for a technical solution are comparable at the moment of decision-making.

All cost consequences of the use of a technical solution over the life span have to be taken into account. This means that the disposal costs at the end of the life span have to be calculated in order to return to the original situation. This concerns final demolition of the building - to have the land freely available again - and the demolition of the components as part of an adaptation activity. In order to have the space available for new partitioning walls and installations, a situation as in new construction has to be created. Disposal costs have to be allocated to the period in which the component is used.

The full-cost picture should take new construction, maintenance and demolition on the level of components into account in a balanced way (figure 2).

All demolition consequences have to be paid for by the user of the component - or the services generated over the economic life span - taking reuse into account. Reuse of the component in another position will lengthen the depreciation period, while recycling may diminish the disposal cost.

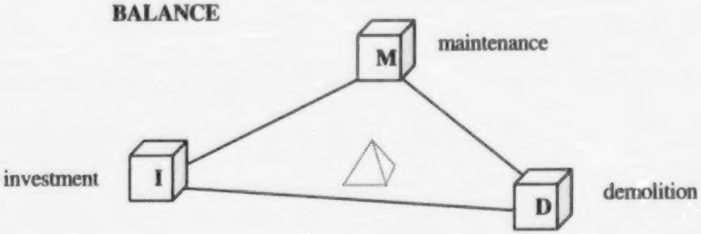


Fig. 2: Costs concerning a solution in balance over life span

4 Decomposition scenario

A building is a set of technical solutions, generating a changing set of services over its total life span, depending on the frequency and level of adaptation activities. Since the production of a changing set of services needs a changing set of solutions, we have to deal with a variety of life spans of components. For each life span the costs of the components have to be allocated to the services concerned. Since the demolition cost as part of an adaptation activity will be (in the future even more) substantial, they have to be estimated carefully, although they may appear only after a period of fifteen years or more.

It will be difficult - or maybe impossible - to predict all adaptation activities over the life span of a building (figure 3) . The future demand for services depends on the market and the underlying primary processes. Since a forecast about the market over a period of more than ten years is hardly possible, the adaptation is likewise difficult to foresee.

When we have split up the adaptation activity in the decomposition part (demolition) and a composition part (like in new construction circumstances) we can split up likewise the prediction of activities in two parts. The decomposition has to be taken into account at the moment of investment in a component, while the replacement installation only has to be decided at the moment of adaptation.

A replacement scenario is not needed, a decomposition scenario (figure 4) will be sufficient for a full-cost picture. (Tempelmans Plat 1985)

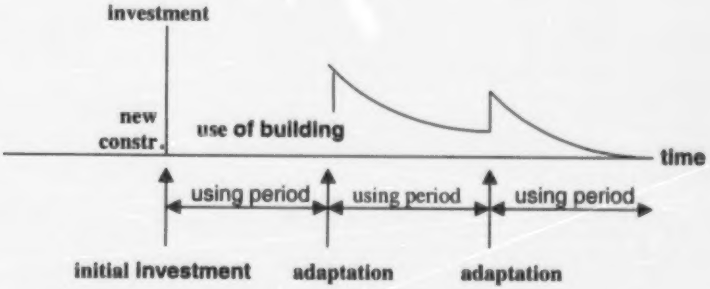


Fig. 3:Momemts of future adoptations to be taken in account

5 Financial decision quantity

The three main types of costs concerning a component (investment, maintenance and demolition) have to be taken into account. This means that they have to be added up to find the total costs of a component and the costs of competing components have to be made comparable. Since the cash flows take place at various moments in time and the life spans of alternative components usually are different, time has to be taken into account in the decision quantity.

All future expenditures (maintenance and demolition) can be discounted to the moment of initial investment or of decision-making. However, the total discounted costs of alternative components can't be compared since they usually concern different economic life spans. When all costs are recalculated on an annual basis (by use of the annuity calculation (Tempelmans Plat 1995) the various annual cost parts may be added up (figure 5), while for different life spans the annual costs (of the services) may be compared.

6 Lengthening of life span

The full-cost consequences may be diminished by technical innovations. However, since for decision-making the life cycle cost consequences (in monetary terms) will be transformed on an annual basis, we have to find out in which way the time element can be influenced in order to diminish the annual costs.

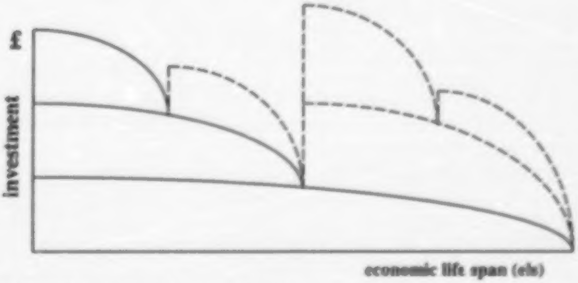


Fig. 4: Full-cost analysis needs a decomposition scenario;
Not a replacement scenario
_______ investments in components in use
----------- expected investment in replacing components

Components of a building will be used in the initial position over a more or less well-defined period. Short periods result in high annual costs, while a miss-forecast regarding long life spans only has marginal consequences. So, it may be cost-effective to reuse a component. Reuse of the component results in a lengthened depreciation period, which may compensate for a higher initial investment to facilitate the future decomposition, avoiding the destruction of the reusable component and components of which the usable period in the initial position has not been expired yet. Connecting components may have to be introduced (Hermans 1995).

Recycling of materials serves as well the goal of reducing the negative environmental cost consequences influences the process of the production of the components, not the economic life span of the component as such.

On the contrary, reuse of components may make relatively high initially environmental consequences acceptable (after recalculation on an annual basis) thus relating costs to services instead of relating them to the production of components. Recycling is additional and does not reduce the need for reuse of components.

7 Open building: demand definition

A large range of technical innovations to avoid negative environmental consequences is available: use of less polluting materials, energy saving solutions and flexible (pre)fabrication systems. However, since we have introduced the recalculation of the (full)cost consequences on an annual basis, the economic life span should be known in order to find the annual cost as basis for decision-making. Only on the basis of a functional demand period scenario a choice out of technical solutions can be made.

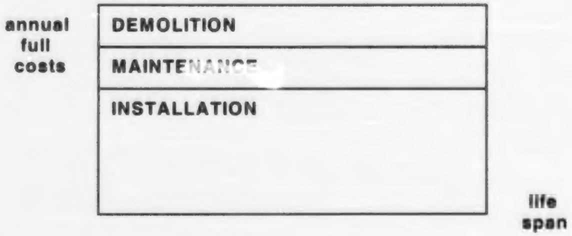


Fig. 5: Anual costs of a component: the three cost components calculated as an average over the economic life span

This demand scenario partly concerns individual user's demand for specific services and partly demand for services to be used by succeeding users of a building: the market demand. As a consequence of this split up in types of demand, variability at the moment of new construction decision-making is supported, as well as flexibility over the life span of the building.

The technical solutions to make variability and flexibility possible is the counterpart of support-infill, with focus basically on the responsibility of the individual user and the society for the built environment. Open Building deals with both sides with focus on demand definition (Ruokolainen and Tempelmans Plat 1998).

8 Limitation of flexibility

As stated before, efficient reuse of components after decomposition is only possible when a decomposition scenario is available. However, such a scenario does not have to be available for all components separately and in detail. Adaptation usually concerns a group of components, depending on the level of adaptation. Adaptation may concern upgrading, renovation or refurbishment.

According to the level of adaptation, the building (or the built environment) may be split up in component groups as illustrated in figure 6. Variability is supported by the installation of 'individual' components in a late stage of the construction process, while flexibility demands for a late installation of components with a short life span (Tempelmans Plat 1993).

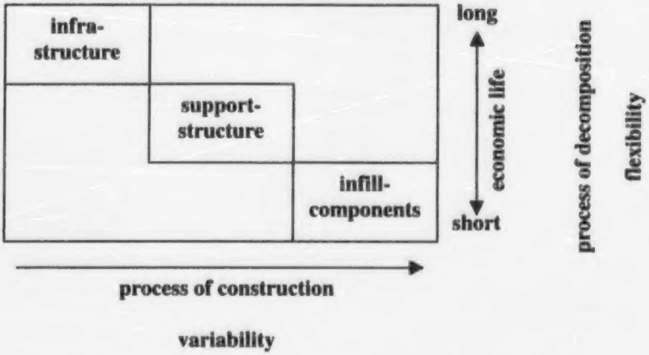


Fig. 6: The built environment split up into component groups installed independently (variability) and replaced with differing frequencies (flexiblity)

We have to be aware of the fact that late installation does not by definition result in easy decomposition and replacement in the future. It depends on the connecting components. Developers of industrialised production systems of components should take this into account.

9 Conclusions

Focusing on minimisation of costs at moments of new construction and of demolition separately is not always efficient. The following points have to be taken into account during in the process of choosing technical solutions for a building.

The cost consequences (full-cost including all environmental consequences) have to be transformed into annual costs on the basis of the economic life span. In this way the various cost elements can be balanced and competing solutions can be compared.

Since disposal costs are (increasingly) substantial, a decomposition scenario should be available in order to be able to allocate disposal costs to the user of the components to be demolished.

Use of flexibility may lengthen the life span of a component, resulting in decreasing depreciation costs and spreading environmental consequences over a longer period. A decomposition scenario is needed for this purpose as well.
Variability at the moment of new construction does not facilitate by definition the flexibility, since the order of replacement has to be the reverse of the order of construction. Still the connection should avoid destruction of the components.

The collection of information about the demand period for services to be generated by building components is poor. As a consequence the basis for a good choice out of solutions is not available, likewise the appropriate development-push is lacking.

10 References

Hermans, M.H. (1995) *Deterioration characteristics of building components.* Ph.D.-thesis Eindhoven University of Technology, Eindhoven, the Netherlands.

Hill, R.C., Bergman, J.C. and Bowen, P.A. (1994) A framework for the attainment of sustainable construction. *Proceedings of the First International Conference on Sustainable Construction.* Tampa, Florida, pp. 13-25.

Hill, R.C. and Bowen, P.A. (1997) Sustainable construction and a framework for attainment. *Construction Management and Economics* 15, pp. 223-239.

Ruokolainen, A. and Tempelmans Plat, H. (1998) *A Decision of Open Building Support System as a Basis for Introduction*, CIB Target Group Open Building, presentation Helsinki, 16 June.

Tempelmans Plat, H. (1982) Micro-economic analysis of the process of design, construction and operation of houses. *IABSE Journal* 14/82, pp. 1-14.

Tempelmans Plat, H. (1985) A financial basis for design participation. *Design Coalition Team*, Vol.1, Eindhoven, pp. 169-188.

Tempelmans Plat, H. (1986) Realistic planning periods as a basis for design and construction decisions. *Organisation of the design process.* IABSE Workshop, Zurich, pp. 9-17.

Tempelmans Plat, H. (1993) Affordable housing in the long run. *4th Rinker conference 'Affordable housing: present and future'*, University of Florida, Gainsville.

Tempelmans Plat, H. (1995) Annual cost and property value calculation based on component level. Conference on financial management of property and construction, Newcastle, Northern Ireland.

Tempelmans Plat, H. (1998) Analysis of the primary process for efficient use of building components. *CIB World Building Congress 'Construction and the Environment'*, Gavle, Sweden, pp. 251-262.

Wyatt, D.P. (1994) Recycling and Serviceabilty: The Twin Approach to Securing Sustainable Construction. *Proceedings of the First International Conference on Sustainable Construction*, Tampa, Florida, pp. 69-78.

205 A NATURAL PROGRESSION: NEGLECT TO DECAY

D.P. Wyatt

University of Brighton, UK

Abstract

From the field work undertaken in connection with service life management practices, and the concern of asset management's contribution to sustainable cities, it is believed that neglect is a critical issue for both current maintenance practices and service life modelling. Further more, the evidence to hand suggest that there is a relationship between neglect and decay that has important implications for both the practice of service life design and building durability. It is also believed that unless there is a proper understanding of all those relationships between decay, neglect and durability, it is unlikely that either service life design or life care management will effectively be able contribute to the longer term goal of sustainable life management. Nor will durability greatly assist those engaged in the maintenance field if they have to continue to struggle with inadequate or limited budgets as they juggle with what is needed to be spent to what is afforded. In fact, budget holders themselves need to also understand that neglect can seriously impair the life quality of their buildings and in a wider context, also impact adversely on the construct of sustainable cities. Nevertheless, it is suggested both through understanding those initiators and drivers of nature's powerful break down systems and bringing established engineering and modelling diagnostic techniques together and applying break down analysis to life care operational management would address many of the current poor building environmental and life care problems. Concluding, it is believed by bringing both ISO 14000 and 9000 together with the emerging ISO 15686 that more purposeful goal for sustainable cities and construction could be set that would address the title of this paper.

Key words. Decay, durability, neglect, service life, break down technology,

Durability of Building Materials and Components 8 (Volume Three). *Edited by M.A. Lacasse and D.J. Vanier*. Published in 1999 by NRC Research Press, Ottawa ON K1A 0R6, Canada. ISBN 0-660-17742-0

'The various creatures of the universe may meet with many external obstacles to their perfect development. but no obstacle can frustrate the development of the universe itself."..."If then we work upwards from the primal chaos to ultimate perfection we must arrive at the nature of the gods' Cicero

1 Times arrow

The life care of the Built environment poses many serious issues and challenges for those promoting both sustainable doctrines and strategies, as well as to those offering life designed buildings or products and materials with or without a service life label. But equally, for those that have to manage this built environment and carry out maintenance on its buildings, find increasingly that their budgets are being slimmed. Yet neither are their building stocks getting younger, nor are their service or life care needs in real time falling and instead, maintenance arrears continue to grow. Or in a built environment sense, is time an illusion? (Coveney and Highfield 1990) or is its neglect a serious omission in the current beliefs of a sustainable future?

Indeed, is it wrong not to link durability with that notion of a building, system component or material and a period of service in use? to time? Do we have in fact a time focus in our building designs for their planning or life care or building replacement? Finally, is there even a simple profile of the age and condition or working life of the building typologies that clearly, can be identified in any city or street set against time and permits one to manage the life care of the built environment?

Perhaps this built environment life problem may be likened to a symphony being continuously played. One musing, ambling, even reflecting upon the birth, life and death of those apparently static and moving images, that contribute to, or go to make up its built environment's buildings, streets, villages, towns and cities. Here, one can suggest that there is both a natural and unnatural progression to a largely unknown terminal building life point, where few buildings are ever likely to escape this final cycle of time > dismission and death.

OK, too many questions? Perhaps, or perhaps not? But silence on life related issues ranging from building redevelopment and replacement of cities to their infrastructures endangers both effective development of the construct of a sustainable modus vivendi and their reinvestment strategies.

So in durability terms, whilst reflecting the passage of changing times in a theme of mortality, its symphony of life and death continues remorselessly on. In short there is an inevitable progression of service life to dismission!

2 An inevitable progression

> *"thy strong Hours indignant worked their wills,*
> *And beat me down and marred and wasted me"*
> Tennyson *Tithonus Lines 18-19*

Inevitably, if one looks long enough, at any built environment, or turns to look at a large city from any strategic vantage point, and look and listen, one can imagine indeed see this symphony being played out. In fact it is not an ode to sustainability, but instead a tribute to entropy where an accumulation or tide of service loss and a reflection of neglect can be found. It is a sound, mixing hope and despair, of inspirational ripples of designers who have learnt to play the life game well. Here their designs' experience generations of people life times, and the quality of material and composition used may give a grace or dignity only marked by age, loss of fitness, or scarred or pocked marked due to durability deficiencies an inevitable end.

One might also pick out to the rich sounds, or listened to those strong sounds and rhythm of new design and construction under way, perhaps being an expression of vibrancy of newness, even a youthful phase! But alas only to find this music being displaced, even drowned out by a creeping darkness of a later movement, capturing that despair of drabness or neglect as maintenance has become ignored and decay laying siege settles in. Listen on, for there is a fourth movement that springs forth, rippling like a renaissance as repair and restoration sally forth with a lightness of well, bringing further life to a building or street or district. Till the final movement of a sombre foreboding, of that spelling of an inevitable demise and death of an area, or of building awaiting its end with or without dignity. Yet one may either leave, or revisit that vantage point, at a future point in time, only to see a different urbanscape with a different rendition of the same symphony of life and death.

In fact, 'this playing of the symphony of built environment score' is cycle of almost an endless disharmony being played out and capturing those struggles to fight back against decay if only to sustain or keep life quality! It also a reflection of that struggle between those urban buildings established from the past and that current or near threatening or new technology of the future, where the wider concerns of sustainable developments and cities and constraints, of resources, waste and unwelcome climatic changes are now appearing upon the urban agenda.

There is in fact in any built environment, a whole series of lives and service life states. There is for example, the life of a city, or community and an economic or physical life of buildings, including their street or city district. There is also a specific life of an individual building, which may be sacrificed before its time due to road widening or new development. In addition, there is the life also of the support systems of a city infrastructure ranging from business, to its servicing utilities. to it.

2.1 Decay

The physical entity of a built environment's behaviour in any urban or rural community is in effect dynamic. Like biological organisms, the respective built environments may in their time or be threatened by disasters, catastrophic events, as well as sink into a local decline, due to economic or migrationary changes. Unlike such organisms however, there is no immediate end date nor a natural transformation of the built environment's waste streams that either fits within an ecological niche, nor in turn sustains other activities..

The life of such built environments nevertheless is a rich mix of lives ranging from current unknown life design proposals on the 'drawing board', to buildings under construction or being renovated, through to those patched or repaired, or just ageing, neglected, obsolete or even abandoned.

Some of these buildings, may in fact, survive many generations and eventually pose other problems like conservation costs. Nevertheless, at the end of the day, one is faced with a simple relationship between decay and neglect as an inevitable part of life. So building life care management itself inevitably faces a diverse range of building both material and systems with varying survivorship and life time qualities and inconsequence there is a need to understand decay.

At the very heart of nature, are very powerful mechanisms or transformers at work which over varying periods of time break all matter down. Here, each transformation pathway has a specific "job to do" so fits a given niche to secure a total break down of a given attribute or attributes of all organic and inorganic materials. So clearly an understanding of the environmental characterisation of this decay process involved is essential in the pursuit of service life design or its management, as is the resistance offered or time taken, is a measure of that material, component, system or building durability quality.

Not only are there dedicated mechanisms or systems to secure this decomposition, or taking apart, but nature may use several systems together to hasten or accelerate an in train decaying transformation. So to try and signal the importance of this in decay-neglect relationship, Figure 1 is included to indicate that there are a number of 'mechanisms or systems' existing which may be 'switched on' in the right conditions.

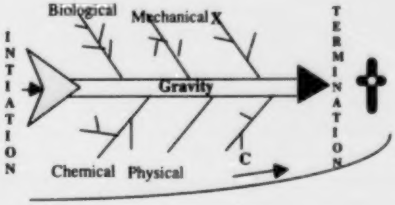


Fig. 1: The natural progression break down options

Simply stated, nature's modus vivendi secures an effective break down technology to deal with and to sustain, the vigour and renewal of life, including in the short term for organic waste break down and in a longer time frame also all inorganic waste break down. The same is true for building as many of these basic or principle mechanisms are at work on and within buildings too! Here, it is the relevant 'initiation switch' that sets the 'degradation-decay process' in train that needs to be identified and understood. Likewise one also needs to understand those behavioural attributes and their environments that accelerate the rates of change. In doing so both would assist manufacturers, designers and asset management practice in their own pursuit of service life.

2.2 Neglect

Time its self then, brings a new dimension to 'life ideas' and understanding (Landsberg 1975), for example, for a building or component, decay may occur where the recovery or protection is insufficient for that environment or operating condition(s). On further examination however, one may come face to face with a peculiar dilemma. Is decay a matter of a natural loss of performance or surface attribute over time, or is it due to neglect? Indeed, is decay not but a function of neglect? If so, at what point then is this failure not to intervene does itself, become neglect?

Nevertheless, the marking down of such surface attributes or qualities, or other imperfections, can also be associated with time served or be seen as part of the ageing process. For example, the relationship of a 'pocked marked rendered building' (pre nineteenth century) hanging on in. or timber decay leaving roofs to collapse. But other issues like ground movement to walls (causing cracking and subsequent instability, through to a falling apart), repeated cycles from frost attack, or simply wasting away (say as corrosion eats more and more into a steel fire escape) are specific examples of neglect even though sometimes unexpected environmental change may ultimately be 'blamed'.

When one looks again at decay and its simple break down mechanisms or system, it is clear that they can gradually become more complex, as more materials with differing service lives and behavioural characteristics are bound together. Even so, there must also come a point when the accumulation of poor or no maintenance, or if one likes ineffective life care can only be attributed to negligence.

Neglect issues or difficulties are to be found in all classes of buildings and for someone conscious of that shabby, indeed 'ageing building' or facility look there will also be at times both dysfunctional operating and poor people environments too. In these situations, serviceability short comings may pose other serious difficulties 'in sustaining' an operating facility to meet its end users expectations-or needs.

Worse still, in a life care sense, is that problem associated with the wrong mix of service life materials, or protection or their relationship viz. a viz. durability characteristics lead to early or regular maintenance or early break down Finally, one might argue that in this decay-neglect domain, delays in responses for intervention or remedial needs may also give rise to a loss of durability (or service loss) which might in turn, lead to eventually a building failure or safety or health risk elsewhere in a building or its systems.

In fact, there is a whole taxonomy of other terms relevant to the decay-durability neglect triangle but the ageing facet of buildings even though it may itself be some what subjective must also be kept in mind. For durability is that 'ability of a building and its parts to perform its required function over a period of time and under the influence of agents' (BSI. 1992) and is a rich picture term. But wouldn't the term 'service loss' be more helpful in pursuing life management or planning a service life design` than decay, or neglect, or durability or obsolescence etc?!

2.3 Service loss

The relationship of neglect and decay is should now be seen as a critical matter for service life building and future sustainable cities. For even a small break down in a protective system, will provide a ledge for a breakdown process to be activated. Indeed, one may argue either by not noticing it, or, if noticing it then ignoring it, is a level of neglect which may become serious. But to relate to either durability or neglect is not enough and it may be more helpful to see the various ravages of time and neglect manifested in decay etc. as a loss of service.

Such service losses may also be exacerbated through a change in a building's environment, for example, arising from misuse, damage, negligence or excessive wear. Here the degree of severity of service loss of a given element on down to a specific component, fitment or surface may its self, range from a minor blemish, up to being unusable or finally leading to a total or catastrophic failure, which in turn may impair or threaten a building's life itself.

But in nature, there is dynamic degradation or a 'loss of service process' where ultimately, every thing breaks down. Inconsequence, it is also reasonable to expect buildings to age and if one likes, 'die' just like any living species or population! A line needs to be drawn between those natural processes of ageing and decay, and that service loss arising from a neglect which may lead to and accelerate a natural decay process. In fact this situation can both be speeded up or slowed down, but seldom reversed (so service loss tends to only grow).

In other cases, service loss or unfitness may be simply attributed to, either a poor location, or an unacceptable space layout, or quality, or the costs of re-configuring the building to meet a new standard of fitness is not seen as 'commercially viable'. Even a site or area's commercial potential for re-development, may hasten the demise of a perfectly serviceable adjoining buildings in that neighbourhood, or cause others to be abandoned, to later to become demolished. So even if technically sound or of robust construction in a 'reasonable state of repair, if it is unwanted by its building owner or rejected by tenants it may by default, be deemed unfit or obsolete.

Inevitably in some situations, end users needs or expectations may have to take second place, as the building life care needs outweigh any financial provision available So in many respects then service loss might be more correctly seen as leading to situations which relate more to serviceability matters too.

3 The eternal triangle

An important relationship may be established between neglect and decay that has important implications for both the practice of service life design and the life or the durability quality found, or planned for in the asset and maintenance domain. Implications of which also spill over into sustainable matters like the carbon deficit problem facing governments and waste and resource management now being legislated for.

Turning now to Figure 2 below, it is suggested that there is in effect an eternal triangle (durability>neglect>decay) that can be mapped e.g. as shown through a quadrant matrix focusing upon the space domain, durability risks, dependencies and finance.

Whilst decay is a natural process once the break down activator point is reached the break down actuators swing into action. So is there also a base line of 'order' that one may find? Like in Nature (Kauffman 1993) must go with the construct of a life, one set at a number of service life levels (for example in Figure 2 from city to joint). Indeed, the issue is that, decay and durability would be better presented, if they could be used for evaluating likely failure analysis of building behaviour changing over time for a building typology as well as for their individual materials or component matrixes.

Nevertheless, the relationship between the service life and its decay (or as preferred here service loss) to the time and the specific point of intervention, (neglect) is in a sense, a resistance to that break down or misuse of that building's, system or materials present. For some promoting life design and service life methodologies this period of time may be seen as a measure of durability.

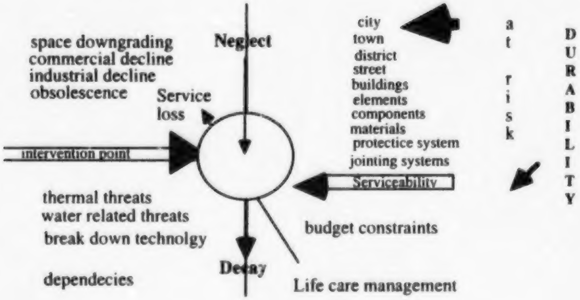

space downgrading
commercial decline
industrial decline
obsolescence
Neglect
Service loss
intervention point
thermal threats
water related threats
break down technolgy
dependecies
Decay
city
town
district
street
buildings
elements
components
materials
protectice system
jointing systems
Serviceability
budget constraints
Life care management
at risk
DURABILITY

Fig. 2: The interdependacies of durability, decay and neglect

Equally, because of the intricacies and problems arising from the variable mixes of materials and components and exposure systems, Nature's break down and the unpredictability of human actions and perceptions (O'Connor 1992) one must also come to grasp a sustainable life construct that is conditioned by a course of future action.

Even so, ultimately, every thing breaks down. It is nature's way as a leveller (e.g. whether through a chemical, biological, physical or mechanical change or equally in terms of survivorship, or death of a population of a buildings, systems components or materials). In that sense, all service losses would also be expected to have a varying decay rates depending' upon a site's surrounding climatic cycles, intensity of prevailing wind, together with that driving rain, air quality and diurnal cycle.

So one now wonders if the works and potential of CIB W86 Building Pathology could not be moved with CIB W94 Designing for durability through to a service life and a life care management framework? What might also help in this suggested move, is that certain life methodologies aspects could be drawn directly from both the electronic and engineering disciplines where research techniques including fault diagnostics and mathematics well advanced.

As it is already an enormous material science and engineering research exists (Siemes 1997: Bamford 1998) and such a research base could with some reinterpretation, be developed for a fuller service life planning (Bourke and Davies 1997). For example, building services might benefit in 'reliability engineering terms', manufacturers components 'populations from survivorship studies together with service life predictions and single material constructions from durability studies.

4 A constructed life

Fitness and durability clearly have a close relationship but more realistically in the life craft and designing for durability or in order to secure product improvement, one would need to also bring as has already been signalled serviceability together with service life planning. This in turn would permit durability and the operational problems to be reviewed as a service loss, so that the relevant dependencies in a given configuration of any building's service lives in the environment are afforded their life with care needs.

Perhaps the real environmental challenge now is to design life manageable buildings that are more closely matched to the properties of their materials and systems lives used in a competitive but regulatory world. But guidance is also called for here too!

Yet significant encouragement can now be seen from three ISO standards which can be linked to advantage to help develop a whole life framework to both respond to the environmental challenge made and deliver life buildings (Figure 3). Here, quality and environmental systems are coming together so one 'business resultant' should be service life design based upon durability which would in turn become part of the Business Excellence thinking and practices next century.

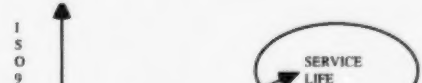


Fig. 3:Management and service life design with a durability focus

The difficulty of predicting for the diverse range and configuration in a building and probability of service loss times to failure whilst frustrating and largely impractical, ignores the tremendous strides being made.

Clearly, service life is a fundamental construct for both those that prepare life designs and life care plans, as well as those that manage the existing portfolio stocks of buildings. So it is also proposed that a service life assessment audit framework like Table 1 is developed.

In turn this would encourage appraisal of both a building development's supply chain and its waste streams as well as bringing both decay and neglect into an operational and strategic analysis.

Whilst space is restricted here, it is still hoped that Table 1 can prompt one to work from top down and bottom up and left to right to also secure a sustainable audit outcome set within the service life serviceability relationship and tenets of this paper. By doing and securing a design life that permits the neglect aspects to be largely removed will in turn contribute to limiting those unwanted CO2 emissions and also bringing the works of CIB 80, TSL 140 and CIB W70 to a wider legislative and practitioner and manufacturer audience.

Table 1 may also be linked to advantage, with service life practice (Wyatt and Luchini 1999) and encourage both the whole development envisaged in ISO 15686 and secure its effective implementation so as to also promote a notion of sustainable cities life care practice.

Table 1: The sustainable life care and planning audit assessment grid

Sustainable cities buildings		
	material resource base drawn upon or changed	
ecological	organic	inorganic
	renewable	non renewable
break down technology	degradable	non degradable
designed asset bldg etc.	life cycle assessment	
	cause and effect analysis	CO2 / NOX -ve +ve
neglect drivers		waste stream
	decay pathway	
service life	durability	service loss
performance settings	reliability	probability
	specification	dependability events
serviceable	accessible	detail quality
	neglect able	interfaces assessment
	clean able	
material resource base	embodied energy	workmanship
space	obsolescence	repairable
	reusable	replaceable
budget for life	recoverable	non recoverable
	inter dependability	waste -ve CO2 accounts
replacement cycle	intervention costs	eco- points
		replacement costs
	risk evaluation	affordable
service life plan	service life profile	life care procedures
Service Life Operational Management		

6 Conclusion

Concluding, it believed that it is incumbent on those developing the service life framework to demonstrate the place neglect and decay have and their adverse impact upon the supply chain for tomorrow's sustainable practices. Indeed, what price is sustainability if the symphony of life and death of the built environments does not become part of the life characterisation and durability-service life model?

Equally, each age must come and hear or rewrite a different interpretation of this life decay- composition, or simply reinterpret their built environment's life symphony obsolescence, neglect decay, building failures and death of building as one technology displaces another. Nevertheless decay and neglect will remind one of both mortality and the imperfect state of development of service life or reliability engineering. Decay beckons, but neglect threatens.

7 References

Bamford D (1998) Probabilistic Performance Based Durability Design of Concrete Structures Taywood Engineering UK Unpublished paper 12pp

Bourke and Davies (1997) factors affecting service life predictions of buildings a discussion paper BRE UK 26PP

BSI (1992) BS 7543 .Guide to durability of buildings and building elements products and components BSI

Cicero The nature of the Gods. Book 11 Translated by H McGregor. Penguin Classic 136-7

Coveney P and Highfield R (1990) The Arrow of Time WH Allen Publ 33

Kauffman SA (1993) The origins of order self organisation and selection in evolution OUP 52-58 & 429-439

Landsberg PT (1975) A matter of time University of Southampton UK 4

O'Connor P (1992) Practical reliability Engineering John Wiley UK 120

Siemes A (1997) Framework For Service Life Prediction Presented at CIB ISO meeting Capri TNO The Netherlands 18pp

Wyatt DP and Luchini A (1998) Service life practice the corner stone of building asset management 8dbmc Vancouver 10pp

Building Industry Authority 1998 New Zealand Approved Document B2 Durability " Code" 19pp ISBN 0-477-01606-5

BSI (1) BS 7527, Classification of environmental conditions Part 3 Section 3 Introduction BSI 8pp

Johnstone I. 1990. Sustainability of Building Stock: An Introduction. Study paper. P/30 School of Architecture. University of Auckland. NZ .

Mattcheck and Breloer (1994) The body language of trees: DOE UK

Nireki T 1996 Concept of Service Life Into Building Activities. Sustainable use of materials Seminar in association with RILEM. BRE 23-24 Sept

Author Index

Aalami, F., 2813
Aarseth, L.I., 1247
Abdelrazig, Y.A., 2429
Abduh, M., 2259
Abraham, D.M., 1257
Abrantes, V., 1040
Adiguzel, I., 1193
Aguilera, J., 246
Ahmad, I., 2395
Ahmet, K., 704
Aikivuori, A.M., 1369
Akbar, R., 2737
AL Shakarchi, Y.J., 1377
Al-Biqami, N., 2327
Albury, D., 201
Alex, A.P., 2407
Al-Hajj, A., 1699, 1739, 1907, 2901
Allwinkle, S.J., 1973
Al-Reshaid, K., 2270
Alshawi, M.A., 2316, 2629, 2651
Al-Tabtabai, H, 2407
Anderson, T., 1813
Andrews, R.J., 269
Ang, G.K.I., 1821
Anumba, C., 2419
Aouad, G., 2629, 2901
Askar, H., 2498
Atkin, B.L., 2791, 2803
Atkinson, B., 943
Augenbroe, G., 2559
Awal, A.S.M.A., 465
Aygun, M., 1833
Bédard, C., 2619
Baig, A., 2609
Bailey, D.M., 1193
Ball, J., 635, 1739
Baronio, G., 538
Bartlett, E.V., 1916
Basheer, P.A.M., 269, 423
Bassi, R.S., 801
Bayramoglu, S., 2452
Becker, R., 1841
Becuzzi, M., 1178
Beliveau, Y., 2601
Bennett, A.F., 1509
Berra, M., 36
Bertolini Cestari, C., 647
Bever, S., 1563
Bhide, S.J., 1382
Binda, L., 527, 538
Blanchard, N., 1070
Blanco-Varela, M.T., 246
Bloomfield, D., 2419
Boettger, T., 814, 864
Bohner, E., 107
Boissier, D., 1299
Bolte, H., 814, 864
Bortz, S.A., 624
Bosack, E.J., 959
Bouchlaghem, N.M., 2945
Bourke, K., 1509
Bourke, K, 1518
Boussabaine, A.H., 1728, 2277
Boutin, F., 550
Boyle, C., 1961
Brandt, E., 658, 669, 1280, 1576, 1813
Breitenbücher, R., 3
Bromblet, P., 550
Brouwer, J., 2012
Brown, A.W., 1973
Buccelato, P.L., 1114
Bungey, J.H., 310
Burn, L.S., 873, 884
Burnett, E.F., 959
Burrow, A.L., 2640
Caner-Saltik, E.N., 613
Cao, H.T., 94
Carcasses, M., 236
Carll, C., 680
Case, M.P., 2579
Cash, C.G., 1083
Cha, S.W., 354
Chamberland, R., 1707
Chan, W.Y., 693, 901
Chang, T.W., 2640
Chang, L.-M., 2429
Chao, L.C., 2287
Chassin, D.P., 2665
Chau, K.W., 2930
Chen, J., 2214
Chen, S.E., 1765
Chernotowich, K., 1093
Chew, M.Y.L., 825
Child, T., 2629
Chiovitti, D., 561
Cho, Y.G., 354
Chown, G.A., 1527
Christian, A.J., 1756
Christiansson, P., 2909
Christie, D., 714
Clarke, J., 2296
Clarke, P., 2296

Clayton, M.J., 2441
Cleven, M., 331
Clift, M., 1916
Çolak, A., 118, 485
Cole, I.S., 693, 901, 1289
Cooper, G., 2537
Crammond, N.J., 139
Cravero, S., 647
Croce, S., 1103, 1595
Crouch, G., 2716
Crowther, P., 1983
Currin, R., 2277
Curtetti, S., 647
Cutting-Decelle, A.F., 2864
Dai, G., 704
Damen, A.A.J., 1848
Daniotti, B., 571
Datta, S., 2640
Davies, H., 1518
Davies, K.A., 1993
Davis, G., 1856
Dawson, A.D., 2920
De Angelis, E., 1103
De Grassi, M., 1585
De Hoog, J., 2033
De Schutter, G., 129
Dikbas, A., 2452
Dotreppe, J.-C., 16
Dubois, A.M., 2864
Dubois, J.E., 2864
Dunbar, T., 2002
Durmisevic, E., 2012
Durmisevic, S., 2012
Eastman, C.M., 2139
Edvardsen, C., 1343
Ekholm, A., 2465
Ekman, T., 280
Emmitt, S., 2059
Eriksson, B., 912, 1602
Fagerlund, G., 212, 1268
Faist, A., 1576
Fang, C.F., 2476
Faraj, I.Z., 2419, 2629
Fazio, R., 269
Finnemore, M., 2836
Fiori, M., 1595
Fischer, M.A., 2737, 2813, 2888
Flourentzou, F., 1280
Foliente, G.C., 756, 1289
Fredel, M.C., 603
Freitas, V. Peixoto De, 1040
Fridqvist, S., 2569
Froese, T.M., 2171, 2476, 2526, 2677, 2747, 2825
Frohnsdorff, G.J., 1537
Fukushima, T., 835
Furusaka, S., 2487
Futcher, K.G., 2306
Gürdal, E., 496
Gandini, A., 1070
Garavaglia, E., 527
Gehlen, C., 3, 409
Genge, G., 1746
Genre, J.L., 1576
Ghanbari, A., 2747
Gilbert, S.G., 714
Gilboa, E., 1666
Gilfillan, J.R., 714
Gonçalves, R., 2377
Gonçalves, M., 561
Goodier, A., 1235
Gorlick, A.L., 2171
Gosav, I., 1392
Goulding, J.S., 2316, 2836
Grew, B.R., 2277
Grew, R.G., 1728
Griffith, E.D., 2579
Grilo, A., 2180
Groot, E.H. de, 970
Guequierre, N.M.J., 2021
Gulikers, J., 376
Gumpertz, W.H., 2068
Gunnarsson, S., 28
Haagenrud, S.E., 1602
Haberecht, P.W., 1403
Haigh, R., 2836
Halliwell, M.A., 139
Ham, M., 1924
Han, C.S., 2590
Hansen, E.J. de Place, 280
Hansen, K.K., 280
Hansen, M.H., 669, 723
Harderup, E., 923
Hashida, H., 256
Hassanain, M.A., 2677
Hazleden, D.G., 734
Hed, G., 1543
Hendriks, N.A., 2033
Henshell, J., 1114
Hermans, M.H., 1848, 1867
Hertlein, B.H., 1203
Hicks, D.K., 2579
Hitchcock, R.J., 2688
Hodges, C.P., 1213
Hosokawa, Y., 475
Hossain, K.M.A., 149
Hovde, P.J., 1247, 1645, 1948
Howard, R.W., 2696
Huovila, P., 1874
Hussin, M.W., 465

Hutchinson, T.W., 2039
Ilic, M., 290
Imamura, H., 746
Isaac, F., 331
Issa, R., 2246
Jónsson, B., 1634
James, R., 2407
Jang, B.S., 354
Jardim-Gonçalves, R., 2180
Jarvis, P., 2419
Jeon, J.H., 256
J, P., 1417
Johnson, M.R., 1615
Johnson, R.E., 2441
Johnstone, I.M., 1718
Jollands, M.C., 884
Jornet, A., 571
Jovanic, P., 290
Kaempfer, W., 36
Kage, T., 320
Kamada, T., 159
Kane, C.D., 1403
Kaneta, T., 2487
Kartam, N., 2270, 2498
Katranuschkov, P., 2189
Kenley, R., 1563
Keršner, Z., 1357
Khatri, R.P., 386
Kiguchi, M., 746
King, G.A., 901
Kirkham, R.J., 1728
Kitsutaka, Y., 300
Kiviniemi, A., 2157
Kloft, K., 1426
Knaebe, M., 680
Kondo, T., 846
Kosovac, B., 2507
Kraft, K.M., 1133
Kristinsson, J., 2021
Kuhne, C., 2813
Kumaran, M.K., 766
Kunz, J.C., 2590
Kus, H., 980
Kyle, B.R., 1223, 1493, 1961, 2002
Lacasse, M.A., 1223, 2547
Laing, R.A., 635, 1739
Lair, J., 1299
Laitinen, J., 2844
Law, D.W., 310
Law, K.H., 2590
Lawanwisut, W., 1357
Lawton, M.D., 989
Le Teno, J.F., 1299
Lee, H.S., 320
Leicester, R.H., 756, 1289
Leira, B., 1436
Leslie, H., 2199
Li, C.Q., 331, 1309
Liebich, T., 2758
Lingård, J., 1436
Lockley, S., 2559
Lombardi, C., 647
Long, A.E, 269
Lopes, J.L.R., 2517
Lounis, Z., 1223
Lubelli, B., 538
Lucchini, A., 1687, 2078
Luciano, J.J., 341
Müller, A., 1022
Ma, Z., 2214
Macdonald, K.A., 436
Mackenzie, C., 1289
Maes, M., 1330
Maggi, P.N., 571
Major, B.M., 1625
Makatayama, M., 932
Makenya, A.R., 1929, 2050
Makepeace, C.B., 1000
Malinauskas, V., 680
Mallory-Hill, S.M., 970
Marie-Victoire, E., 581
Marshall, R.R., 1011
Marshall, S.J., 1746
Marteinsson, B., 1634
Matsushita, F., 159
Mayer, P.D., 1447
Mc Cafferty, E., 269
McGeorge, W.D., 1765
McGraw, K.D., 2579
Meland, I.S., 170
Miletic, S., 290
Millard, S.G., 310
Miller, E.D., 341
Miltenberger, M.A., 341
Mirza, M.S., 269
Molina, C., 527
Mommessin, M., 2864
Montagna, R., 180
Morgan, D.R., 46
Morris, P.I., 734
Morten, B., 2452
Moser, K., 1319
Moss, G.W., 1552
Motohashi, K., 846, 854
Mu, L., 190
Murphree, E.L. Jr., 2224
Naaranoja, M., 2705
Naji, B., 201
Nakai, T., 846
Nakamura, N., 300

Nakayama, M., 593
Nandakumar, N., 222
Nassar, K.M., 2601
Naticchia, B., 1457, 1585
Nawa, T., 256
Nazarski, D.G., 1679
Needham, J.P., 2224
Nelson, R., 1000
Nes, S., 1645
Nesje, A., 1436, 1961
Newton, L.A., 1756
Ng, F.F., 2930
Ngowi, A.B., 2089
Nicolajsen, A., 723
Nireki, T., 1509
Nofal, M., 766
Noguchi, T., 320
Norén, J., 780
Norberg, P., 980, 1030
Nordström, K., 212
Northwood, D.O., 436
Noumowe, A.N., 932
Novák, D., 1357
Nunoo, C., 2395
O'Brien, M.J., 2327, 2609
Ödeen, K., 107, 780
Ogle, R., 1000
Oh, B.H., 354
Ohkubo, T., 932
Ojwaka, P.M., 2876
Ong, K.C.G., 222
Ottosen, P.S., 2724
Ovstaas, G., 46
Ozkan, E., 1156
Ozsariyildiz, S.S., 2234
Pfunder, I., 1773
Page, I.C., 1509
Palomo, A., 246
Parasonis, J., 2099
Paterson, D.A., 901
Paulsen, J., 1467
Pauri, M.G., 180
Payer, D.R., 2547
Pepenar, I., 231
Pierson, M., 515
Piette, P.A., 2688
Pimentão, J.P., 2180, 2377
Plenty, T., 1765
Poli, T., 571
Pollastro, C., 1178
Porter, J.F., 515
Puertas, F., 246
Pulakka, S., 2710
Pullen, S.F., 1778
Puterman, M., 1666
Quenard, D., 236
Racutanu, G., 56
Rankin, G.I.B., 423
Rankin, J.H., 2526
Rasool, H.A., 1377
Raupach, M., 365, 376
Ravetta, F., 1124
Ravi, M., 2619
Re Cecconi, F., 571, 1124
Rejna, M.G., 571, 1475
Renzullo, A., 561
Rezgui, Y., 2537
Rigamonti, G., 571
Riontino, C., 246
Ripberger, A., 2813
Rivard, H., 2338
Roberts, K., 2039
Robertsen, E., 2107
Rocca, P., 538
Romagna, R.H., 1022
Roman, H.R., 603
Roman, L.M.F., 603
Rosenfeld, Y., 1666
Rossiter, W.J., Jr., 1133
Rowe, D.P., 1881
Rowlinson, S., 2306
Rubaud, M., 1070
Rudbeck, C., 1051, 1148
Russell, A.D., 2348
Russell, D.P., 423
Rutila, D.A., 2068
Ryell, J., 71
Sægrov, S., 1436
Saad, I.M.H., 2358
Sabbioni, C., 246
Sahal, N., 1156
Sandberg, P.I., 923
Sariyildiz, S., 2012
Sarshar, M., 2836
Sartori, P., 1166, 1178
Sasaki, M., 593
Saunders, G.K., 1235
Sayil, B., 118, 485, 496
Scartozzi, U., 180
Scherer, R.J., 2189
Schiessl, P., 3
Scholten, N., 1939
Schueremans, L., 83, 1330
Schulz, U., 864
Scott, J., 1739
Selkowitz, S.E., 2688
Shen, Q.P., 1655
Shibata, S., 159
Shirlaw, M.R., 445
Shohet, I.M., 1666

Showalter, W.E., 2716
Siemes, T., 3, 1343
Silva, D.A., 603
Sinclair, S.P., 1728
Sinyayev, O.V., 1485
Sirivivatnanon, V., 94, 386
Sjöström, C.H., 1537, 1602
Skancke, T., 1602
Skibniewski, M.J., 2259
Slavenburg, S.F., 2370
Smith, D.K., 1787
Snape, P., 943
Sobanjo, J.O., 1798
Song, Y., 2441
Soronis, G., 1537, 1929, 2050
Sotos, P.G., 680
Sousa, M., 1040
Sousa, P., 2180, 2377
Sousa-Coutinho, J., 453
Sri Ravindrarajah, R., 505
Staub, S., 2888
Steiger-Garção, A., 2180, 2377
Strand, S.M., 1948
Sund, E., 1436
Svendsen, S., 1148
Szigeti, F., 1856
Tadeu, L., 2180
Tanaka, E., 846
Tanaka, K., 256
Tang, L., 399
Tavukçuoglu, A., 613
Tempelmans Plat, H., 2118
Tenwolde, A., 680
Teplý, B., 1357
Teruzzi, T., 571
Texier, A., 581
Thabet, W.Y., 2386, 2939
Thomas, M.D.A., 71
Thompson, N., 1907
Thompson, S.V., 1062
Thorpe, A., 2945
Tiganis, B.E., 873
Tiso, A., 1103
Tjandraatmadja, G.F., 884
Tolman, F.P., 2234
Tomosawa, F., 320
Toumbakari, E.E., 246
Trinidad, G.S., 693, 901
Trubiroha, P., 864
Trunk, P.R., 71
Tucker, S.N., 1509
Turk, Z., 2776
Tzonev, S.N., 1679
Udaipurwala, A.H., 2348
Underwood, J., 2629
Utgenannt, P., 399
Vakola, M., 2537
Vallee, F., 1070
Van Balen, K., 246
Van Bronswijk, A., 1924
Van Den Hoonaard, J., 3
Van Gemert, D., 83, 1330
Van Straten, T.M.H., 2370
Vangel, M.G., 1133
Vanier, D.J., 1223, 2507, 2547, 2677
Venta, G.J., 515
Vestergaard, M., 787
Vries, B. de, 970
Wörner, J.D., 1426
Wakefield, R.R., 2386, 2939
Waly, A.F., 2386, 2939
Watanabe, K., 932
Waugh, L.M., 2526
Weir, G.F., 1973
Westberg, K., 912
Wetzel, C., 1280
Weydert, R., 409
Whyte, J.K., 2945
Wirahadikusumah, R., 1257
Wirt, D., 2716
Wiseman, A., 1493
Wittchen, K.B., 1576
Wix, J., 2724, 2758
Woerner, J.-D., 28
Wonneberger, B., 624
Woodbury, R.F., 2640
Wornell, P., 1447
Wyatt, D.P., 1615, 1687, 1821, 1893, 1929,
  2078, 2126
Xianming, 190
Yitmen, I., 2452
Young, M.E., 635, 1739
Yu, K.Q., 2825, 2724
Yusuf, F., 2651
Zappia, G., 246
Zhu, Y., 2246
Zurale, M.M., 1382
Zutphen, R.H.M. van, 970

Subject Index

Vol. 1: Pages 1–898; Vol. 2: Pages 899-1560; Vol. 3: Pages 1561–2136; Vol. 4: Pages 2137–2954

3D CAD, 2939
3D modeling, 2930
4D planning, 2939
AAC (*autoclaved aerated concrete*), 107, 159, 980
ABC (*acrylonitrile butadiene*), 1083
ABS (*acrylonitrile butadiene styrene*), 873
accelerated ageing, 180, 814, 854
accelerated weathering, 624, 835, 1083
acid rain, 864
acrylic resins, 485
adhesion system, 846
adhesive testing, 1133
adhesives, organic elastic, 846
AEC/FM, 2157
after-effect, 1485
ageing, 1070
  accelerated, 814, 854
  heat, 873, 1093
  natural, 854, 1166, 1178
  simulated, 515
agents, 912
aggregate, fine, 475
aggressive attack, 231, 1392
air barrier, 959, 1000
air permeability, 423
airborne salinity, 901
airports, 2224
analytic hierarchy process, 190
annuity, 1645
anode, 365, 376
appraisal, 222, 1773
architecture, 2601, 2338, 2619
artificial intelligence, 2419
asphalt, 1093
assessment, 269, 2876
  accrued value, 1765
  building, 1280, 1993
asset management, 1193, 1563, 1756, 1778, 1881, 2296
atmospheric corrosion, 901
audit, 1552, 1746
automation, 2590
bar codes, 2716
Bayesian updating, 1357
bearing strength, 505
bevel siding, 746
bibliography, 2547
biological decay, 989
bituminous membranes, 1156
break down technology, 2126
brick masonry, 1062
brickwork, 571
bridge management, 56
bridges, 16, 56
brief, 2651, 2651
budget forecast, 1707
budgets, 1280
building, 766, 1051, 1509, 1532, 1634, 2214
  characterization, 1707
  codes, 1527
  element, 1833
  envelope, 693, 766, 1000, 1051
  management, 2696
  materials, durability, 1103
  products, 1417, 2059
built environment, 1436
business strategy, 2316
CAD, 2465, 2557, 2569, 2579, 2590, 2696, 2945
calcium aluminate, 246
calcium carbonate, 159
calcium silicate, 246
calculations, 912, 923
capability maturity model, 2836
capital costs, 1746
carbon dioxide, 801
carbonate aggregate, 139
carbonation of concrete, 1357
carbonation rate, 423
carbonation test, accelerated, 423
carbonation, 159, 246, 256, 386, 409, 423, 465
case-based reasoning, 2526
cathode, 365, 376
causal path analysis, 1973
CD-ROM, 2547
cement board, 515
cement paste, 246
cement, type of, 170
cementing material, 386
ceramic tile, 603, 846
chamber test, 246
chemical analysis, 593
chemical attack, 465
chemical-physical compatibility, 1457
chloride, 376, 399
  deposition, 1403
  diffusion coefficient, 341
  diffusion, 71, 341
  exposure, 280
  flux, 341
  migration, 341
  penetration, 83, 94, 386
  ponding, 341
choice criterion, 2118
cladding, 624
  building, 624
  exterior, 1666
classification, 2465, 2517
cleaning, 581
clear coating, 854
climate simulator, 723
climate, 923
climatic chamber, 180
coating systems, offshore, 1907
coatings, 801
codes, building, 1527
commissioning, 2688
communication, 2270, 2377, 2920
compact disk, 2547
compatibility compliance, 1475
complex information, 2864
component database, 1447
component model, 2609
component, building, 1319
composite steel-concrete construction, 16
compressibility, 825
compressive strength, 505
computer, 2277, 2338, 2776
  integrated construction, 2171, 2452, 2537
  simulation, 835
  software, 2665
computer aided design (*see CAD*)
computer-aided learning, 2930
computer-aided priorization, 1655
computerization, 1707
computerized environment, 2651
concrete, 3, 129, 222, 236, 256, 280, 310, 341, 365, 376, 399, 436, 445, 453, 581, 801, 1203
  cover, 409
  elements control measurements, 2099
  freezing and thawing, 436
  frost resistance, 118, 212, 1268
  high performance, 71, 212, 465, 2476
  light weight, 149, 505
  penetration of fuel in, 28
  Portland cement, 290
  quality, 16
  reinforced, 190, 231, 365, 376, 1343, 1493
  resistivity, 409
CONCUR, 2234
concurrent engineering, 2189
condensation, 1000
condition appraisals, 1615
condition assessment, 1235, 1602, 2677
condition monitoring, 1203
condition states, 1257
condition survey, 1645
connectors, 693
conservation, 1625
constructability, 2498, 2939
constructed facilities, 1532
construction, 734, 766, 1756, 1939, 2068, 2214, 2224,

2277, 2306, 2338, 2386, 2601, 2716, 2888, 2939
  building, 2487
  cost, 2407
  industry, 2327
  management information systems, 2747
  management, 2747
  method, 2487
  new, 1011
  organizations, 2395
  projects, 2901
contamination, 593, 1377
control, 2277
controller, 2377
copy, 550
core tests, 222
correlation, 814, 825
corrosion, 83, 94, 290, 300, 331, 341, 365, 376, 693, 1203
  development, 16
  percentage, 320
  rate, 310, 1062, 1403
  test, accelerated, 354
  prediction of chemical, 36
  rebar 320
  steel, 269
corrugates, 201
cost, 1011, 1040
  control, 2888
  estimating, 1787, 2476, 2825, 2844
  modelling, 1699, 1728
cost-benefit evaluation, 2705
cost-effective, 1148
costs, operation, 1699
  running, 1699, 1728
  whole life, 1518, 1916
cracking, 16, 46, 129, 159, 280, 300, 1022
creative design, 2776
creep resistance, concrete, 1133
creep, concrete, 1485
curtain wall, 593
damage, 56, 527
dampness, 613
data, 2277
  collection, 1223, 2716
  exchange, 2139, 2157, 2370, 2758
  modelling, 2724, 2825
  quality, 1298
  sets, 1298
  standards, 2157
  warehousing, 2395
database, 56, 635, 2498
  active, 2609
  management, 2395
  product and component, 2864
decay, 746, 756, 2126
decision making, 2395, 2487
decision support, 970, 1765, 2419, 2452, 2517
deconstruction, 1961
deflection, 734
degradation, 714, 873
  agents, 1543
  construction, 1436
  environment, 1543
de-icing salts, 399
demand definition, 2118
demolition, 2021
density distribution, 1319
depletion of ozone layer, 835
depreciation period of buildings, 1679
design, 923, 2068, 2465, 2569, 2888, 2939
  agenda, 1821
  building, 2710
  criteria capture and reuse, 2579
  database, 2609
  detail, 2059
  generation, 2945
  intent, 2688
  life, 1509, 2078, 2107
  model based, 2579
  preliminary, 2619
  process, 2920
  stage, 1841
design/build, 2370, 2487
deterioration, 835, 1203, 1257, 1309, 1357, 1493, 1527, 1666
determination method, 1939
developing countries, 2050
diagnosis, 1666
  building, 1576, 2665
diagnostic, 231
diffusion of innovations, 2059
diffusion, 386, 593, 801
diffusivity, 269, 436, 932
dimensions, 1841
disassembly, 1983
discrete event simulation, 2287
dismantling, 1961
  design for, 2021
disruption, 1615
distributed object environment, 2590
document
  content analysis of, 2517
  management, 2370
  model, 2246
  production, 2579
dose–response function, 912
drainage, 734
drawings, as-built, 2441
drip caps, 723
drying shrinkage, 159, 1022
drying, 236, 734
durability, 3, 36, 107, 129, 159, 170, 280, 376, 409, 423, 445, 453, 465, 505, 515, 561, 571, 624, 647, 658, 669, 723, 734, 756, 766, 780, 782, 873, 959 1040, 1062, 1070, 1148, 1298, 1343, 1377, 1382, 1426, 1532, 1552, 1602, 1687, 1813, 1821, 1924, 2039, 2059, 2068, 2078, 2107, 2126, 2547
  design, 1289
  tests (freezing and thawing test), 475
  building components, 1679
  design for, 2021
  physical, 180
dwelling services, 1718
dynamic buffer zone, 1000
dynamic modulus, 256
dynamic response, 310
dynamic schema evolution, 2569
eco-labelling, 1993
economic impact, 1961
economical rationality, 1369
economics, building, 1699
EDI, 2327
efficiency, 2296
elastic recovery, 825
elasticity, 1485
elastometric sealants, 814
electrical measurement, 1030
electrode configuration, 1030
electronic document management, 2537
electronic networking technology, 2259
end-of-life scenario, 2021
energy
  consumption, 2033
  dispersive analysis), 290
  performance, 1576
  requirements, total, 1778
engineering, 1841, 2338, 2601
enterprise resource planning, 2370
envelope, building, 693, 766, 1000, 1051
environment, 1907
  degradation, 246
  design, 2002
  engineering, building, 970
  impact, 1778, 2021
  risk factoring mapping, 1602
  supply chain audit, 1929
environmentally optimal thickness, 2033

EP (ethylene propylene), **1083**
EPDM roof membranes, **1133**
epoxy coated reinforcement, **46**
epoxy resins, **485, 496**
erection, **2099**
EVA (ethylene vinyl acetate), **1083**
evaluation, **1634, 2640**
excavation operation, **2287**
execution, **2107**
expanded polystyrene, **505**
expert systems, **1447, 1235, 2776**
exposure testing, **1124, 1417**
fabrication compliance, **1475**
facades, **1040**
    performance, **943**
facilities, **1798, 2696**
    design, **2579**
    operations, **2441**
    owners, **1787**
facilities management, **1699, 1756, 1765, 1798, 1856, 2224, 2441, 2517, 2724**
factor method, **1247, 1518**
failure, **1011, 1298, 1369, 1382, 1527**
    analysis, **1666**
    damage, **766**
    mode effects and criticality analysis, **1916, 1298**
    modes, **1330**
    patterns, **505, 1447**
    prediction, **1457**
    probability, **1330, 1357**
fatigue, **256**
feedback system, **2498**
FEM (finite element method), **320, 603**
fibre reinforced polymers, **1493**
fibre reinforcement, **201, 280**
fibres, **1382**
Fick's second law of diffusion, **341**
field exposure, **980**
field inspection, **714, 1634**
field testing, **159, 624, 780**
filling stations, **28**
films, free, **814**
fire, **149**
flexibility, **2012**
flexural strength, **320**
flexure test, **256**
floor coverings, **1467**
fluoropolymer, **854**
fly ash, **290**
forecasting, **1369**
formwork
    controlled permeability, **453**
    design, **2407**
foundation, **1011**
fracture mechanics, **300**
fracture, **766**
FRAMEplus, **1062**
full-scale models, **538**
function modelling, **2803**
functional
    analysis, **1298**
    compliance analysis, **1475**
    compliance, **1475**
    requirements, **515, 1527, 1856**
fungi, **766, 989**
fuzzy tests, **1798**
galvanostatic pulse, **310**
gate keeper, **1929**
generative design, **2640**
genetic algorithm, **2407**
genetic reasoning, **2737**
GIS, **1602, 1778**
geometric, **1030, 2601**
geographical information systems (see GIS)
glass fiber scrim reinforcement, **515**
graphical modelling, **2224**
green specifications, **2002**
gutters, **680**
gypsum, **485, 496**
healthy indoor climate, **1924**
heat ageing, **873, 1093**
high performance concrete, **71, 212, 465, 2476**
high-rise buildings, **2476**
highway, **399**
historic building, **581**
house building, **2945**
house wrap, **959**
housing, **693, 766**
    management, **1707**
    stock, **1718**
humidity, **669**
hydration products, **118**
hydration, heat of, **465**
hydrostatic pressure, **1156**
hypermedia, **2246, 2930**
IAI, **2157, 2171, 2452, 2569, 2579, 2590, 2629, 2688, 2677, 2724, 2758, 2825**
IFC (see IAI)
image processing, **2429**
impact behaviour, **201**
importance sampling, **1357**
indexing, automatic, **2507**
indoor environment quality, **1576**
information dimensions, **2517**
information entropy, **190**
information systems, **2569**
    life-cycle, **2688**
    interactive, **2864**
    modelling, **2651, 2747, 2758**
    overload, **2059**
    structure, **2224**
information technology, **2214, 2224, 2270, 2296, 2306, 2327, 2338, 2688, 2705, 2716, 2747, 2758, 2791, 2844, 2901**
infrared imaging, **180, 613**
infrastructure, **1257, 1436**
inherent compliance, **1475**
innovation, **2945**
insects, **714**
in-situ strength, **222**
in-situ testing, **269**
inspection systems, **1213**
installation, **959**
insulation, **2033**
    performance, **2033**
    external thermal, **1070**
integrated systems, **2419**
    construction management, **2526**
    design system, **2619**
    distributed construction, **2629**
    logistics support, **1916**
integration, **2180, 2348, 2377, 2579, 2737, 2791, 2888, 2920**
intelligent systems, **2419**
interactive, **2547**
International Alliance for Interoperability (see IAI)
internet, **2259, 2327, 2358, 2452, 2507, 2547**
interoperability, **2180, 2377, 2465**
intervention measures, **231**
intranet, **2259**
in-use condition, **1634**
investigations, building, **1576**
ISO 9000, **1756**
ISO/CD 1586, **1319**
joint models, **814**
keyphrases, **2547**
knowledge
    bank, **2370**
    engineering, **2844**
    representation, **2224**
knowledge-based systems, **2189, 2419**
laboratory testing, **624**
laboratory-carbonated sample, **159**
laminates, **1382**
laser, **581**
Laser–Doppler vibrometry, **180**
leisure centres, **1728**
lesson learned, **2498**
life audit, **1929**
life care, **1893, 2078**
    management, **1687**
life cycle, **766, 1213, 1773, 1787, 1833**
    analysis, **2039**

  assessment, **1467, 1821, 1929, 1948, 1973, 1983, 2021**
  costing model, **1907**
  costs, **71, 1051, 1493, 1509, 1532, 1625, 1699, 1739, 1756, 1787, 1798, 1881, 1993, 2021, 2901**
  design, **1867**
  economics, **1493, 1679, 2710**
  management, **1436, 1813**
life expectancy, **28**
life span
  building components, **1867**
  economic, **2118**
life, endurance, **354**
lime-pozzolan paste, **118**
limits of deviation, **2099**
load, combined mechanical and environmental, **280**
load-bearing capacity, **1330**
local climate, **912**
local government, **1563**
long-term performance, **980**
macrocell, **376**
maintenance, **613, 1213, 1257, 1309, 1319, 1436, 1509, 1615, 1634, 1728, 1813, 1916, 2107**
  budgeting, **1645**
  costs, **1699**
  fabric,**1907**
  functions, **2348**
  information, **1848**
  information systems, **2452**
  management, **1602, 1666, 2441, 2677, 2724**
  management, building, **2705, 2517**
  management, risk-based, **1223**
  planning, **1645, 1655**
  planning, building, **1585**
  strategies, **1821**
mapping, **613**
marine environment, **129, 1403**
Markovian models, **1257**
masonry veneer steel stud wall (MVSS), **1062**
masonry, **527, 538, 561, 1330**
  brick, **1062**
mass loss, **236**
massive structures, **129**
material and energy flow, **1426**
materials, **766, 1939, 2068**
  properties, **1213**
  building, **912, 1532, 1948, 2050, 2089**
  durability of, **2089**
measurements, **236**
mechanical pressurization, **1000**
mechanical strengths, **118**
mechanical testing, **1417**
mechanical tests (compressive and bending tests), **475**
membrane assembly temperature, **1093**
membranes, polymer modified bituminous, **1103**
meta classification, **2909**
metagame analysis, **2487**
metamodelling, **2517**
meteorological data, **912**
micro-climate, **912**
microstructure, **159, 256, 1070**
mineral admixtures, **354**
mineral wool, **2033**
models, **2696**
  building, **2139**
modelling, **766, 932, 1289, 2107, 2180, 2776, 2909**
  parametric, **2601**
  physical and mathematical, **527**
modern movement buildings, **1625**
modified bitumen, **1156**
  APP, **1166, 1178**
  membranes, **1093**
moisture, **766, 923, 1148**
  content, **669, 680, 693, 1030**
  monitoring, **980**
  sensors, **669**
mold, **766, 989**
molecular changes, **884**
monitoring, **365, 613**
mortar, **256, 550, 932**
  linings, **170**
  wall, **746**
moulding, **550**
multidisciplinary work, **2012**
multilayer panels, **180**
multimedia, **2270, 2358, 2909, 2930**
multi-objective optimization, **1223**
multiple indicators, **1833**
multiple views, **2737**
multi-storey office building, **2619**
national strategy, **2002**
neural networks, **2287, 2429, 2476**
non-destructive testing, **222, 1203**
non-shared information, **2246**
numerical analysis, **593, 704**
numerical simulation, **376**
object interworking, **2537**
object oriented programming, **2287**
object oriented modelling, **2537, 2569, 2579**
objective-based codes, **1527**
on-line, **2270**
open building, **2118**
operational effectiveness, **1615**
operations management, **2677**
optimization, **1369, 2407**
organic corrosion-inhibiting admixture, **341**
organic elastic adhesives, **846**
organizational change, **2296**
oriented information, **1848**
outsourcing, **2557**
paint, **658**
palm oil fuel ash, **465**
parking garages, **1493**
pathologies, **1040**
pattern recognition, **2429**
penetration, **222**
performance, **561, 571, 1051, 1417, 1527, 1813, 1856, 1893, 2876**
  appraisal, **1595, 1833**
  approach, **1867**
  assurance, **2688**
  audit, **2078**
  auditing, **1687**
  based procurement, **1821**
  based design, **970**
  concept, **1532, 1867**
  metrics, **2688**
  over time, **1552, 1867**
  ranking, **1083**
  requirements, **1417, 1848, 1939, 2677**
  standards, **1156**
permeability, **71, 236, 269, 801**
phenomenological perception, **2296**
photo ageing, **864**
photodegradation, **884**
photon flux, **835**
photo-oxidation, **884**
physical characterisation, **884**
physical testing, **1083**
planning, **2677, 2939**
  and control, **2180**
  asset and maintenance, **1625**
  construction, **2526**
plaster, **107, 1022**
plasticity, **1485**
plausibility, **1298**
polycarbonate, **884**
polyethylene-glycol methacrylate, **854**
polymer-cement, **1070**
polymeric finishing materials, **835**
polystyrene foam, **496**
polyurethane foam, **2033**
pore structure, **118**
porous materials, **1030**
portfolio assessment, **1856**
Portland cement, **445**
positioning systems, **2377**
poultice, **581**

- *pozzolan*, 465
- *practices, contemporary building*, 2089
- *precast concrete*, 1114, 1595, 2487
- *prediction models*, 1447
- *predictive maintenance*, 1203
- *prioritization*, 1213, 1615, 1848
- *probabilistic design*, 3, 1343
  - *methods*, 1257
  - *models*, 1280
- *process analysis*, 2677
- *process improvement*, 2836
- *process maturity*, 2836
- *process modelling*, 2139, 2171, 2651, 2747, 2791, 2844, 2803, 2813, 2876
- *process protocol*, 2316
- *processing tool*, 1707
- *procurement*, 1893
  - *construction*, 1518
- *product data management*, 2189
- *product data technology* (*PDT*), 2234
- *product modelling*, 1223, 2157, 2171, 2569, 2609, 2677, 2737, 2747, 2776, 2813
  - *building*, 2844
- *product reuse*, 2021
- *productivity*, 2277
  - *analysis*, 2348
  - *construction*, 2287
- *products, building*, 1417, 2059
- *products, concrete*, 475
- *programs*, 1615
- *project*, 2386, 2888
  - *control*, 2813
  - *database*, 2629
  - *decision-making*, 2199
  - *delivery system*, 2259
  - *information exchange*, 2199
  - *information*, 2791
  - *management*, 2214, 2358, 2747
  - *models*, 2825
  - *planning*, 2813
  - *teams*, 2791
  - *views*, 2348
- *properties, physical*, 873
- *protection by design*, 723
- *prototype*, 2224
- *public buildings*, 1655
- *public sector*, 1467
- *pull-out test*, 714
- *PVC* (*polyvinyl chloride*), 1083, 1178
- *qualitative simulation*, 1457
- *quality*, 1756
  - *assessment*, 2429
  - *control*, 436
  - *management, total*, 1856
- *rain screen*, 1000
- *rainfall distribution*, 943
- *RC beam*, 320
- *real estate*, 1773
  - *management*, 1821
  - *management, corporate*, 2517
- *reconstruction*, 1773
- *recycling*, 475, 1961, 1983
  - *material*, 2021
- *reengineering*, 2844, 2876
- *refurbishment*, 647, 1576, 1595
  - *investment*, 1280
- *regression analysis*, 901
- *regulation*, 1939
- *rehabilitation*, 1257, 1436, 1679, 1718, 1798
  - *cost*, 1707
- *reinforced composites*, 1382
- *reinforcement*
  - *corrosion of*, 1357
  - *passive and active*, 16
- *reinforcing bar*, 300
- *reinforcing steel*, 331
- *relative humidity*, 932
- *reliability*, 83, 1357, 1916
  - *analysis*, 1330
  - *building*, 2099
  - *building structures*, 1679
- *remedial action*, 989
- *remote collaboration*, 2557
- *renovation*, 658
- *repair*
  - *costs*, 1746
  - *performance of*, 1625
  - *techniques*, 1625
- *repeatability*, 1203
- *repeated load*, 256
- *replacement*, 1773
- *representation*, 2640
- *requirements management*, 1867
- *residential*, 1011
  - *building*, 1746
- *residual service life*, 1280
  - *prediction*, 190
- *residual strength*, 331, 741
- *resin*, 550, 1382
- *resistance*, 801, 1030
- *response surface technique*, 1330
- *retrofitting*, 222, 1040
- *reuse*, 1961, 1983
- *reverse propagation*, 2696
- *risk*, 1518
  - *management*, 2059
  - *risk-based maintenance management*, 1223
- *road environment*, 399
- *roofs*, 1083, 1114, 1133, 1166, 1178
  - *acrylic*, 864
  - *design, sustainable*, 2039
  - *flat*, 1103, 1148, 1235
  - *management*, 1213
  - *overhangs, effect of*, 680
  - *single ply*, 1083
  - *systems*, 1193, 2677
- *rules*, 2609
- *rust*, 746 (*see also corrosion*)
- *safety*, 923, 1841
- *salt crystallization*, 527, 538
- *salts, de-icing*, 399
- *sandblasting*, 581
- *sandstone*, 635
- *saturation*, 236
- *scaling*, 436
- *scenarios*, 2864
- *scheduling*, 2386, 2825, 2888, 2939
  - *automatic*, 1585
- *sea state*, 901
- *sealants*, 46, 825
  - *building*, 864
- *seams*, 1133
- *self-desiccation*, 212
- *sensor*, 365
- *service delivery*, 1563
- *service life*, 56, 71, 94, 341, 746, 1051, 1103, 1124, 1268, 1298, 1319, 1392, 1417, 1426, 1436, 1467, 1527, 1532, 1552, 1602, 1625, 1666, 1679, 1687, 1813, 1821, 1856, 1881, 1893, 1916, 1948, 1983, 2107, 2068, 2126 2547
  - *actual*, 1369
  - *component*, 1707
  - *design*, 423
  - *estimates*, 1518, 1948
  - *estimating*, 56, 1247
  - *mapping*, 1687
  - *nominal*, 1298
  - *performance*, 1193
  - *planning*, 1543, 2078
  - *predicted*, 46, 835
  - *prediction models*, 1369
  - *prediction*, 83, 571, 1280, 1493, 1543
  - *remaining*, 1447
- *serviceability*, 1615, 1813, 1821, 1841, 1856, 1893, 1929, 2876
  - *limit states*, 16
- *severe environments*, 354
- *sewer systems*, 1257
  - *pipe, concrete*, 36
- *shared project information*, 2246
- *shear strength*, 1377
- *shotcrete*, 180
- *shrinkage, drying*, 159, 1022

siding, hardboard, **680**
silica fume, **436**
silicone adhesive, **593**
silicone resins, **485**
simulation, **1718**, **1787**, **2601**
site test, **538**
slabs, concrete, **28**
slag, ground granulated blast furnace, **139**
social benefits, **1718**
software implementation, **2157**
software interoperability, **2688**, **2758**
sorption model, **704**
sorptivity, **386**
specifications, **436**, **2246**
  construction standard, **846**
  design element, **2629**
  substitution, **2059**
standards, **1051**, **1518**, **1532**, **1552**, **1916**, **1929**, **1939**, **2180**, **2370**
statistical methods, **1436**
statistics, **1728**
steam curing, **475**
steel, **365**, **376**, **1403**
  bar, corrosion of, **354**
  mild, **901**
  reinforcement, **310**
  stud, **1062**
STEP, **2139**, **2629**
step-by-step principle, **1247**
stochastic, **1645**
  approach, **1247**
  performance model, **1223**
  processes, **527**
stone, **593**, **624**
  cleaning, **635**, **1739**
  decay, **635**, **1739**
  finishing, **846**
  repair, **635**
  structures, **613**
structures, **647**, **714**, **1392**, **2619**, **2776**
  analysis, **1298**
  assessment, **310**
  concrete, **331**, **1309**
  reliability, **1309**
  system, durability of, **1718**
stucco, **445**
styrene-ethylene-butylene-styrene modified asphalt, **1093**
subfloor, **1403**
sulfate resisting Portland cement, **139**
sulfuric acid attack, biogenous, **36**
sulphate attack, **139**, **386**
sulphation, **246**
supply chain, **1893**, **1916**, **2803**
  management, **1929**
  processes, **2836**
surface analysis, **884**
surface deposit mapping, **943**
survey, **1124**, **2338**
surveying, **1576**
sustainability, **1961**, **1973**, **1983**, **2002**
  building, **1532**, **1687**, **1867**, **2050**
  cities, **1893**
  design, **1787**, **2050**, **2089**
  development, **2012**, **2039**
  roof system design, **2039**
  roofing, **2039**
Swedish building stock, **1467**
symbolic modulus, **1485**
systems, building, **1746**
tapes, adhesive, **1133**
technical rationality, **1369**
temperature, **932**
temporal data, **2909**
tension softening, **300**
termite, **756**
testing, **409**, **538**, **453**, **669**, **782**, **825**, **1156**
thaumasite, **139**
thermal decay, **1103**
thermal stresses, **603**
thermoplastic membranes, **1083**
thesaurus, **2507**
thin walled composite, **149**
three-tier client-server architecture, **2629**
timber, **647**, **693**, **714**, **756**, **1289**
  moisture content, **704**
time compression factor, **814**
time-accelerated test, **36**
time-of-wetness, **1062**
time-to-failure, **1133**
Tobermorite, **159**
T-peel adhesion, **1093**
TPO (*thermoplastic olefin*), **1083**
traffic noise barrier, **780**
training, information technology, **2316**
transportation structures, **71**
tunnel, **3**
ultrasonic pulse velocity, **222**
ultraviolet light, **835**
urban infrastructure, **1778**
usage phase, **1467**
use, building, **1867**
user needs, **1856**
utility assessment, **2259**
validation, **2619**
value chain, **2803**
value engineering, **2498**
value management, **1881**
value measurement, multiple attribute, **2259**
variables processing, **1319**
vent, **1403**
ventilated air gap, **1148**
ventilation diagnostics, **2665**
virtual building, **2909**, **2920**
virtual construction, **2939**
virtual reality modeling language (*VRML*), **2930**
virtual reality, **2901**, **2945**
viscoelasticity, **1485**
visual decay forms, **613**
volcanic pumice, **149**
wall systems, **723**, **766**, **846**
waste concrete, **475**
water
  absorption, **212**
  penetration, **561**, **989**
  pipes, **170**
  repellents, **83**, **561**, **538**, **980**
  services, **1778**
  vapour, **801**
  vapour sorption isotherms, **159**
waterproofing, **1156**
  materials, **647**
  membranes, **1103**, **1166**, **1178**
weather barrier, **959**
weather resistance, **445**
weatherability, **864**
weathering, **1070**
  accelerated, **624**, **1083**
  natural, **624**, **814**
web-based project management, **2452**
Weibull distribution, **1447**
WETCORR, **980**, **912**
whole life economy, **1813**
whole life performance, **1881**, **1916**
wind, **959**
  direction, **901**
windows, **658**
  systems, **1973**
  washing, **1114**
wireless, **2277**
wood, **658**, **734**, **756**, **766**, **780**, **854**, **1030**
  frame, **766**
  protection by design, **782**
  rot, **766**, **989**
  pressure impregnated, **723**
wooden house, **746**
workflow, **2370**
workplace productivity, **1787**
WWW (*World Wide Web*), **2270**, **2590**, **2864**
XML (*extended markup language*), **2246**
zinc, **1403**